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DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, Secretary
BUREAU OF MINES
VAN. H. MANNING, Director

BLACK DAMP IN MINES

BY

G. A. BURRELL, I. W. ROBERTSON
AND
G. G. OBERFELL

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BLACK DAMP IN MINES.

By G. A. Burrell, I. W. Robertson, and G. G. Oberfell.

INTRODUCTION.

The Bureau of Mines, in pursuing investigations looking to greater safety in mining, has analyzed samples of the air in many different coal mines in the United States, and has studied the analyses. This report presents the results of one phase of this study and shows how atmospheric air, after entering a coal mine, loses oxygen and gains carbon dioxide with resulting formation of so-called black damp. Also the report discusses the effects of the constituents of black damp on men, on the burning of oil and acetylene lamps, and on the explosibility of methane.

The term "black damp" was and still is widely used to designate accumulations of carbon dioxide, but a more exact definition of black damp, as Haldane, the English physiologist, has pointed out, is an accumulation of carbon dioxide and nitrogen in proportions larger than those found in atmospheric air. The reasons for preferring Haldane's definition are given on succeeding pages.

COMPARISON OF ATMOSPHERIC AIR WITH MINE AIR.

When atmospheric air enters a coal mine, it changes in composition according to (1) the velocity with which it traverses the workings; (2) the amount of coal with which it comes in contact—that is, the extent of the mine workings that it traverses; (3) the gaseous nature of the seam; (4) the tendency of the coal to absorb oxygen; and (5) the temperature and wetness of the mine.

As regards the details mentioned, the governing conditions are as follows: (1) Other things being equal, more carbon dioxide and methane are present and there is a greater deficiency of oxygen at places where the air is still, as at working faces and in old workings. (2) The purity of the air depends on the distance it has traveled, so that in a well-ventilated mine the air is purer at working faces near the shaft than at those that are remote. In the same mine the air will be fresher and purer when the mine is ventilated by a split system than when the air traverses each working face and entry. (3) Some mines vary greatly as regards the generation of methane. Methane is not only dangerously inflammable, but, if introduced in large proportions at some parts of a mine, it lowers the oxygen content of the atmosphere to such an extent that the atmosphere will not support the combustion of lamps or even will not support life. (4) Coals differ as regards their power of absorbing oxygen. Absorption of oxygen is never accompanied by a molecular proportional increase in the amount of carbon dioxide produced, for the oxygen combines with certain unsaturated hydrocarbon compounds in the coal. (5) The amount of water vapor in air is principally a function of the temperature of the air; hence, if air that is comparatively dry enters a mine, if the temperature of the mine is higher than the outside temperature, and if the mine is comparatively wet, then the proportion of water vapor taken up by the mine air may be greatly in excess of that in the atmospheric air.

In mines other than coal mines the chief factors that decrease the oxygen content of the mine air are the velocity of the air current, the extent of the workings traversed by the air, the amount of oxygen taken from the air, and the amount of carbon dioxide or other suffocating gases added to it by the decay of mine timbers, the burning of lights, the breath of men and of animals, and the oxidation of minerals, and also by the gases given off from the rocks penetrated.

COMPOSITION OF THE ATMOSPHERE.

Pure dry air as analyzed contains, by volume, 20.93 per cent of oxygen, 0.03 per cent of carbon dioxide, and 79.04 per cent of nitrogen. Included in the nitrogen content are the four inactive gases—argon, krypton, neon, and xenon. These, with the exception of argon, which constitutes 0.94 per cent of air, are present in exceedingly small proportions. Water vapor is also present in the air, varying greatly in amount at different times and in different places. The temperature of the air is the most important factor in determining water-vapor content.

Different analysts have found that pure air differs slightly in composition from the figures given above, but these variations, with the exception of carbon dioxide, for which the occasional variation may be one or two hundredths of 1 per cent, are due to unavoidable inaccuracies in the analyses. Pure air has the same composition by volume at sea level or on mountain peaks or at heights that may be reached only with balloons. This constancy of composition is brought about by a gaseous exchange between the plant and the animal life, because animals throw off carbon dioxide, whereas all the higher forms of plant life absorb it. All of the carbon dioxide of the living world comes from the 0.03 per cent of carbon dioxide in the atmosphere.

TRANSFER OF OXYGEN AND CARBON DIOXIDE IN BREATHING.

When a man breathes, air enters the lungs. The oxygen from the air passes through the delicate lining membrane of the air cells of the lungs into the blood, where it forms a loose chemical combination with the hæmoglobin in the red corpuscles. Thus loosely combined the oxygen is conveyed to the heart, and thence through the arteries to the capillaries, where it separates from the hæmoglobin and passes through the capillary walls to the tissues, where it is consumed. Carbon dioxide passes from the tissues in a corresponding manner, forms a loose combination (as bicarbonate and possibly other compounds) in the blood and is conveyed by the veins to the lungs, where the combinations break down, and the carbon dioxide passes from the lining membrane of the lungs into the breath.

EFFECTS ON MAN OF VARIATIONS IN COMPOSITION AND AMOUNT OF AIR.

EFFECT OF CARBON DIOXIDE.

As regards the amount of carbon dioxide present that may give rise to symptoms of poisoning, Haldane and Smith[a] carried out a number of experiments on animals and men and demonstrated that these symptoms did not begin to appear till 3 to 4 per cent of the gas was present, when the breathing became slightly affected. Men can, however, go on working for a considerable time in this atmosphere without feeling serious discomfort, although they will certainly become quickly fatigued, and great exertion will cause panting; but Haldane kept animals for weeks in this atmosphere without causing them much inconvenience. A proportion of 7 to 8 per cent causes more apparent symptoms, and with 10 per cent the distress is great, the headache becomes much more severe, there is marked dyspnœa, throbbing pulse, and flushing of the face, and the gas begins to have a stupefying effect. With 12 to 15 per cent, cerebral symptoms appear, and the patient soon becomes unconscious. Death may take place after exposure for several hours to 25 per cent, but Haldane found that some animals may breathe a much greater percentage, even 50 per cent, without dying.

The concentration of carbon dioxide in the lungs is automatically regulated, so that it is remarkably constant, practically without relation to changes in the rate of breathing, provided respiration is not forced. This relation was shown by experiments of Haldane and Priestly,[a] the results of which follow:

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[a] Haldane, J. S., and Smith, Lorain, Physiological effects of air vitiated by respiration: Jour. Path. Bact., vol. 1, 1892, p. 174.

Results of experiments of Haldane and Priestly to determine relation between rapidity of respiration and concentration of carbon dioxide in lungs.

Subject.	Respirations per minute.	Proportion of carbon dioxide in alveolar air—		
		At end of inspiration.	At end of expiration.	Mean.
		Per cent.	*Per cent.*	*Per cent.*
J. S. Haldane	9	5.59	5.87	5.73
	19	5.56	5.70	5.63
Do	9	5.33	5.47	5.40
	20	5.44	5.60	5.52
J. G. Priestly	10.5	5.95	6.74	6.35
	30	5.98	6.05	6.02

Even during muscular exertion Haldane[a] and Priestly found that when the percentage of carbon dioxide in the inspired air was increased to 4 or 5 per cent the partial pressure of the carbon dioxide in the air in the air cells of the lungs was practically constant.

The effect of breathing air containing carbon dioxide is to stimulate the so-called respiratory center in the brain and increase the depth of breathing. This increase in the depth of breathing is brought about by the smallest increase in the percentage of carbon dioxide in the inspired air, and is sufficient to keep constant the percentage of carbon dioxide in the alveoli, or air cells, of the lungs. This response of the respiratory center of the brain to carbon dioxide is seen during muscular work. The latter increases the production of carbon dioxide in the arterial blood, resulting in an involuntarily increased depth of breathing proportionate to the extra production of carbon dioxide, hence there results the rapid breathing (hyperpnœa) seen during exercise. So small an amount of carbon dioxide in the atmosphere as 1 or 2 per cent does not materially endanger the life and comfort of those who breathe it, but does decrease their efficiency as workmen. A man is forced to breathe a larger amount of air in a given time, and this breathing consumes energy just as the work he is doing consumes energy.

An increase of 50 per cent in the amount of air breathed is brought about by the presence of 1.4 per cent CO_2 in the inspired air, according to Douglas, Haldane, Henderson, and Schneider.[b] They add that panting then becomes excessive even if a man does a great deal less muscular work than he could do in normal air.

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[a] Haldane, J. S., and Priestly, J. G., The regulation of the lung ventilation: Jour. Physiol., vol. 32, 1905, p. 225.

[b] Douglas, C. G., Haldane, J. S., Henderson, Y., and Schneider, E. C., Physiological observations made on Pikes Peak, Colo.: Philos. Trans. Roy. Soc. London, ser. B, vol. 203, February, 1913, pp. 220–221.

EFFECT OF DIMINISHED OXYGEN SUPPLY.

Abnormally rapid breathing is also brought about by want of oxygen. In some individuals such breathing is produced when the oxygen percentage of the air is less than 13 (normally about 21) per cent. Rapid breathing is produced much more quickly by excess of carbon dioxide than by a corresponding deficiency of oxygen. The important practical point to remember is that rapid breathing caused by carbon dioxide starts long before danger becomes serious, whereas when it is produced as the result of a deficiency of oxygen it is a grave symptom and points to serious danger.

Bert[a] showed that the abnormal symptoms and dangers associated with low barometric pressure depend, not on the diminished mechanical pressure, but on the diminished partial pressure of the oxygen and consequent imperfect aeration of the arterial blood with oxygen. He found that definite symptoms of want of oxygen began to appear whenever the partial pressure of the oxygen was reduced below a certain limit. Thus at ordinary atmospheric pressure a cat died when the proportion of oxygen was reduced to about 4.5 per cent, or a partial pressure of 4.5 per cent of an atmosphere. At a barometric pressure of 0.5 atmosphere, on the other hand, the animal died when the oxygen was reduced to about 9 per cent, which is again 4.5 per cent of an atmosphere, and at a pressure of 2 atmospheres a reduction of the oxygen percentage to 2.25 per cent was needed. He established the general law that the physiological action of a gas depends on its partial pressure, and further showed that the percentage by volume of oxygen taken up by the blood either in the lungs or outside the body depends on the partial pressure of the oxygen, and is greatly reduced when the lowering of oxygen pressure becomes dangerous.

When men or animals, even though at rest, are subjected to atmospheres deficient in oxygen or at low pressures, marked hyperpnœa is rapidly produced. Marked hyperpnœa caused by oxygen want is only temporary, and is due to the fact that the want aids carbon dioxide in exciting the respiratory center.[b] For a short time the proportion of carbon dioxide already present in the blood and tissues is more than enough to excite the center. When the excess has been eliminated by a temporary hyperpnœa the breathing again becomes quiet, and if the transition to want of oxygen is gradual the temporary marked hyperpnœa is not noticed. Want of oxygen without the aid of carbon dioxide does not excite the respiratory center at all.[c]

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[a] Bert, Paul, La pression barométriqué, 1878.

[b] Haldane, J. S., and Poulton, E. P., Effects of want of oxygen on respiration: Jour. Physiol., vol. 37, 1908, p. 390.

[c] Henderson, Yandell, Apnœa and shock: Am. Jour. Physiol., vol. 25, 1910, pp. 310, 385.

EFFECT OF AIR AT HIGH ALTITUDES.

Men ascend to high altitudes where the air is "thin," and consequently the partial pressure of the oxygen as compared with that at sea level is small. Under the same conditions of temperature and pressure the expansion of different gases is practically the same. Hence the proportion by volume of oxygen, nitrogen, etc., in air remains the same, no matter what the altitude, but the percentage by weight varies as the pressure changes. Air at sea level and at a barometric pressure of 760 mm. contains, by weight, about 23 per cent of oxygen, but at half that pressure, or 380 mm., contains only half of 23 per cent, or 11.5 per cent.

The table following shows the barometric pressures at different heights, also the partial pressure of the oxygen—that is, the percentage of oxygen that would correspond to the same attenuation of air at sea level.

Partial pressures of oxygen corresponding to different barometric pressures.

Altitude.		Inches of mercury.	Barometric pressure, mm. of Hg.	Partial pressure of oxygen compared to pressure at sea level.
Meters.	Feet.			
0	0	30.0	760	21
1,000	3,280	26.0	670	18.5
2,000	6,560	23.4	592	16.3
3,000	9,840	20.6	522	14.4
4,000	12,290	18.2	460	12.7
5,000	16,405	16.0	406	11.2
6,000	19,580	15.4	358	9.9
7,000	22,965	12.5	316	8.7
8,000	26,245	11.0	279	7.7

In explorations of the Himalayas the Duc d'Abruzzi and his companions climbed to a height of 24,580 feet, the barometric pressure being 312 mm., and the partial pressure of the oxygen about 8 per cent.[a] At this point the explorers felt no discomfort during rest and seemingly did not experience any difficulty in performing the work required in climbing.

However, after the explorers had lived for several weeks at a height of 17,000 feet above sea level, the atmosphere did work some harmful effects, revealed only gradually in a slow decrease of appetite and consequent lack of nourishment, but without any disturbance of digestion. Of course, ultimately this insufficient nourishment would have caused a lowering of vitality, loss of flesh, and a certain amount of anæmia. However, the effect was so slow that even at the end of two months the men were able to make long marches without becoming excessively tired.

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[a] Filippi, Di Filippo de, Karakoram and western Himalaya, 1909, pp. 361–368.

Many people are affected at a height of 6,000 to 9,000 feet. Everybody suffers from shortness of breath and fatigue at 12,000 feet, and serious symptoms frequently develop at 16,000 feet. At this height the partial pressure of the oxygen corresponds to air at sea level containing about 11.5 per cent oxygen. However, people can live at very high altitudes. In Peru, Bolivia, and northern Chile a large proportion of the population live above 10,000 feet. The elevation of the observatory at El Mista, in the Andes, is about 19,000 feet. It takes time, however, for the body to adapt itself to such an attenuation of the air. A person unaccustomed to it and suddenly plunged into such an atmosphere would experience severe distress.

EFFECT OF BREATHING A DECREASING OXYGEN SUPPLY.

Some instructive experiments on this point, in which one of the authors participated, are described in Technical Paper 122[a] and summarized in Technical Paper 109.[b] The experiments were made under the direction of Yandell Henderson, professor of physiology at Yale University.

A man breathed air in and out of a bag having a capacity of about 70 liters. By means of a can of caustic potash inserted between the man's mouth and the bag the exhaled carbon dioxide was removed. Under these conditions, of course, the oxygen content of the air breathed gradually fell. When it had fallen to about 7 per cent the subject lost consciousness for a few seconds.

The mode of action of the "oxygen want" is instructive. The subject felt no urgent warning symptoms up to the time of collapse. In fact, he wanted to continue, and just before collapse made a show of resistance against discontinuing the experiment. He felt no real distress until some time after the experiment. The next day he was decidedly unwell.

EFFECT OF A MINE ATMOSPHERE LOW IN OXYGEN.

In its insidious action "oxygen want" acts as carbon monoxide frequently does, that is, when the oxygen is slowly decreased. One difficulty in comparing the mode of action of the two lies in the scarcity of experimental data regarding the effects on men of atmospheres containing small percentages of oxygen.

Much light is thrown on the action of the two gases by an accident that occurred in the Lodge Mill Colliery, Huddersfield, England.[c]

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[a] Burrell, G. A., and Oberfell, G. G., Effects of atmospheres deficient in oxygen on small animals and on men: Tech. Paper 122, Bureau of Mines, 1915, pp. 7-9.

[b] Burrell, G. A., and Oberfell, G. G., Composition of natural gas used in 25 cities, with a discussion of the properties of natural gas: Tech. Paper 109, Bureau of Mines, 1915, pp. 16-18.

[c] Lloyd, W. D., The use of rescue apparatus at Lodge Mill Colliery, Huddersfield: Coll. Guard., vol. 106, Nov. 7, 1913, p. 957.

Three men were in a disused part of the mine, and two of them, A and B, were overcome by the black damp at 3.30 a. m. A third, C, was overcome at 4 a. m. in an attempt to rescue his comrades. At 1 p. m. of the same day rescuers equipped with breathing apparatus removed C and about an hour later removed A. A little later B was found dead. Both A and C were in a critical condition but still breathing. A died three days later. The air in which the men were overcome contained a high percentage of methane and had a correspondingly low oxygen content. Haldane,[a] in speaking of this disaster, made the following comment:

> All the facts recorded indicate that the men were overcome by the insufficiency in the oxygen percentage of the air. There was no reason to suspect the presence of carbon monoxide as there was no gob fire or heating. In addition, the blood of the dead man was black, not red, as it would have been if death had been due to carbon monoxide. It is probable that sufficient fire damp was present to reduce the oxygen to 7 or 8 per cent. The fact that A did not recover was due to exactly the same cause which often prevents men recovering after severe carbon monoxide poisoning. The tissues have been severely damaged by the prolonged exposure to dearth of oxygen, so that, although the oxygen supply is completely restored, recovery is doubtful. In the case of A the post-mortem examination revealed the fact that the heart was dilated. Probably the heart muscles and the other tissues were in a condition of fatty degeneration caused by the want of oxygen. The writer has seen other similar cases of dilatation simulating severe heart disease, and only slowly recovering after prolonged exposure to carbon monoxide poisoning. So far as he is aware, however, this is the only recorded case of death, after partial recovery, from exposure to an atmosphere which was simply deficient in oxygen, apart from the presence of carbon monoxide.

EFFECT OF ATMOSPHERES LOW IN OXYGEN ON CANARIES AND MICE.

Some experiments to determine the effect of atmospheres low in oxygen on mice and canaries, performed by the authors of this bulletin, are described in Technical Paper 122.[b] In conducting the experiments, atmospheres containing various percentages of nitrogen and oxygen were prepared in 10-liter bell jars. For the nitrogen supply a tank containing nitrogen with a small percentage of oxygen was obtained. The atmosphere in the tank analyzed 97.8 per cent nitrogen and 2.2 per cent oxygen.

In the experiments with canaries three birds, designated A, B, and C, were used. Tabulated results of the experiments follow:

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[a] Haldane, J. S., Note on paper by W. D. Lloyd: Coll. Guard., vol. 106, Nov. 7, 1913, pp. 957–958.

[b] Burrell, G. A., and Oberfell, G. G., Effect of atmospheres deficient in oxygen on small animals and on men: Tech. Paper 122, 1915, pp. 5–6.

TABLE 1.—*Results of experiments to determine effect on canaries of breathing atmospheres low in oxygen.*

Trial No.	Canary.	Composition of atmosphere during experiment.						Effect on canary.
		At beginning.			At end.			
		Oxygen.	Nitrogen.	Carbon dioxide.	Oxygen.	Nitrogen.	Carbon dioxide.	
		P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	
1	B.....	9.42	90.48	0.10	8.50	90.90	0.60	Immediate distress evinced by rapid breathing, open bill, and tendency to wabble. In 10 minutes the bird was seemingly in normal condition except for slightly increased rate of breathing. It was removed from the atmosphere after 1 hour.
2	C.....	9.25	90.65	.10	....	....	....	Behaved similarly to canary B in trial 1.
3	A.....	7.65	92.25	.10	7.55	92.05	.40	Showed immediate distress by panting and unsteadiness, but did not collapse. It did not evince any more distress than canary B in trial 1. It was left in the atmosphere for 1 hour.
4	C.....	7.83	92.07	.10	....	....	....	Collapsed as soon as it was placed in the atmosphere. It breathed very slowly, with eyes and bill closed, but recovered its normal state in less than a minute after it had been removed to fresh air.
5	A.....	7.10	92.80	.10	....	....	....	Showed distress, but did not collapse in 20 minutes. When canary C was placed in the atmosphere it immediately collapsed.

The next experiments were made with white mice instead of canaries. Tabulated results follow.

TABLE 2.—*Results of experiments to determine effect on white mice of atmospheres deficient in oxygen.*

Trial No.	Composition of atmosphere during experiment.						Effect on mouse.
	At beginning.			At end.			
	Oxygen.	Nitrogen.	Carbon dioxide.	Oxygen.	Nitrogen.	Carbon dioxide.	
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	
1	7.07	92.83	0.10	7.75	92.05	0.20	Showed immediate symptoms of distress. At times it appeared normal and again appeared sluggish. Did not collapse. It was left in the atmosphere 1 hour.
2	6.89	93.01	.10	7.12	92.78	.10	Same as on mouse in trial 1.
3	6.70	93.00	.30	....	....	....	Same as on mice in trials 1 and 2.
4	5.90	94.00	.10	....	....	....	Showed immediate distress and collapsed in 6 minutes. One minute after removal from the atmosphere it was on its feet.

GENERAL COMMENTS ON TESTS.

Canaries show some distress in atmospheres containing 9.4 per cent oxygen. The distress is more pronounced in atmospheres containing as low as 7.6 or 7.8 per cent, but even in an atmosphere containing as little as 7.1 per cent of oxygen they may or may not collapse. Mice are slightly more resistant to atmospheres low in oxygen. In an atmosphere containing about 7 per cent of oxygen they show some distress and become more or less sluggish if left in it. One mouse resisted an atmosphere containing as little as 5.9 per cent of oxygen before it collapsed. With that percentage, collapse did not occur until the mouse had been exposed for 6 minutes.

EFFECTS OF OXYGEN DEFICIENCY AS SHOWING RELATIVE VALUE OF BIRDS AND MICE IN EXPLORING MINES.

From the foregoing experiments on birds, mice, and men, it will be seen that oxygen want begins to affect men in about the same time as it does mice and canaries, and the percentages that cause collapse are not much different. Animals differ slightly as to their resistance to collapse in atmospheres low in oxygen, and presumably the same is true of men. The fact is evident that exploring parties in mines can not satisfactorily use birds and mice to detect atmospheres low in oxygen.

Canaries are of chief value in showing by their behavior the presence of carbon monoxide. Afterdamp may contain enough oxygen, about 17 per cent, to support the flame of an oil-fed lamp, so that exploring parties entering it would have no means of knowing that the air is low in oxygen, although the presence of dangerous percentages of carbon monoxide could be detected by the action of the canaries, even if it is not shown by the flame of the safety lamp. When mine-exploring parties, unequipped with breathing apparatus, reach an atmosphere in which oil lamps are extinguished, they are likely to proceed close to or into dangerous atmospheres if they advance farther, even if provided with canaries for detecting vitiated air. The acetylene lamp does not become extinguished until the proportion of oxygen falls to about 13 per cent. In such an atmosphere a party is not in immediate danger, although close at hand there may be atmospheres considerably lower in oxygen, and hence dangerous, into which a person might walk in a very short time. However, any party exploring a mine after a disaster and using canaries would also be equipped with oil safety lamps and with electric lamps, so that acetylene lamps need hardly be considered.

EFFECT OF TEMPERATURE AND MOISTURE ON MAN.

The temperature of the atmosphere is important in that it governs the capacity of air for absorbing moisture. A hot, moist atmosphere prevents the evaporation of perspiration from the body. If, in addition, hot, moist air is stationary, it becomes entangled between the clothing and skin, and becomes warmed to body temperature. Hence, the body can not lose heat to the air, and the skin becomes warmed and bathed in perspiration. Putting a fan in operation whirls the hot, warm air away from the body and allows cooler air to take its place, accounting for the beneficial effect of a fan in a room, even if fresh outside air is not finding access. If the wet-bulb temperature is 99° F. (body temperature), the body will not lose heat, but if the external temperature is 79° or 69° F., perspiration can evaporate. Experience has taught that when the wet-bulb temperature exceeds 75° F. the amount of work that a man can do begins to fall off. Ventilating engineers in this country try to arrange ventilating equipment so that a wet-bulb temperature of 72° F. will not be exceeded. They aim to maintain a relative humidity varying between 30 and 80 per cent. The standard for dry-bulb temperature is about 68° F.

Cadman and Whalley,[a] in an investigation of ventilation in English coal mines, observed that at a wet-bulb temperature of 72° F. heavy clothing was removed and only light clothing worn. At 80° F. hard work was possible, provided the maximum body surface was exposed, the capacity for work being greatly increased, however, if a current of air or a breeze passed over the body. With wet-bulb temperatures of from 80° to 85° F. work was seriously affected, and hard work was almost impossible.

VENTILATION OF BUILDINGS ABOVE GROUND.

In designing the ventilation systems of public buildings, houses, and other places where people meet, the effects of carbon dioxide and oxygen are subordinated to other conditions, such as temperature, humidity, and keeping the air moving. At sea level, in the most ill-ventilated room, the weight of the oxygen in a cubic foot of the air never is as low as in the open air at high altitudes, and it is seldom that the carbon dioxide content rises above 0.10 or 0.20 per cent, although the air in such a room may be unfit to breathe.

The ventilation in rooms is not essentially a matter of correcting diminished oxygen or increased carbon dioxide but of keeping the temperature, the relative moisture, and the movement of the air in a proper state. However, in the ventilation of rooms where people congregate the carbon dioxide and the oxygen tests may be excellent criterions of the state of ventilation. Haldane and Osborne[a] have investigated the ventilation of a large number of workshops and factories and have recommended that the standard of ventilation be such that the proportion of carbon dioxide does not exceed 0.12 per cent during daylight or 0.20 per cent after dark when oil or gas is used for lighting. The carbon dioxide percentage is specified because its determination is easy and its presence a sign that there is no free ventilation and that the air tends to become humid and warm. However, the vitiation of air in overcrowded rooms may arise from the products of disease, want of cleanliness of the occupants, or the room itself. In fact, air that, judged by the carbon dioxide standard, is sufficiently pure, may be exceedingly impure when judged by the number of microorganisms in it, and vice versa. The test of smell, of feeling of comfort or discomfort, in breathing the air of a room may give results equally at variance with the carbonic acid test. Some people are more influenced by odor, others by an increased quantity of carbon dioxide or moisture or an increased temperature.

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[a] Cadman, John, and Whalley, E. B., Report of an inquiry into the ventilation of coal mines and the methods of examining for fire damp: Royal Commission on Mines, England, 1909, p. 4.

Men who habitually work in bad air that is not sufficiently tainted to cause acute symptoms may suffer from slight anæmia, with disinclination for work, rapid breathing on exertion, lassitude, loss of appetite, and other symptoms of indigestion. Return to work in better air, however, soon puts them right.

VENTILATION CONDITIONS IN MINES.

The foregoing discussion of the factors to be considered in ventilation studies has largely to do with conditions aboveground and in public halls, houses, and other places where people congregate. With modifications it is applicable to conditions in coal and in other mines. In meetinghouses aboveground the carbon dioxide in excess of the proportion found in atmospheric air is principally derived from exhaled air, and if present, even in proportions as high as 0.20 per cent, is usually a sign of stagnant air and poor ventilation. It has been found that this proportion of carbon dioxide usually accompanies very bad ventilation in that the air is stagnant and oppressive, with perhaps high temperature and the odor of perspiring bodies.

In coal mines carbon dioxide arises principally from the action of the air on the coal, and 0.2 to 0.3 per cent is frequently found in the cool, swiftly moving air of returns, where 50,000 or more cubic feet of air is passing per minute and the wet-bulb or dry-bulb temperature does not exceed 65° F. The relative humidity may be high, almost 100 per cent in many mines, owing to artificial methods of watering to allay coal dust, but where the temperatures are not high the high humidity has no bad effect. Hence a proportion of carbon dioxide that would be easily tolerated in a coal mine might be indicative of extremely poor ventilation in the room of a house.

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[a] Haldane, J. S., and Osborne, O. O., Ventilation of factories and workshops: English Govt. Blue Book, 1902.

A similar statement applies to oxygen. The oxygen content is scarcely ever normal in a coal mine, owing to the absorption of oxygen by the coal; in fact, a diminution of 1 per cent is not uncommon. Such a diminution in an assembly room would usually be accompanied by intolerable conditions of ventilation. However, the proportion of oxygen can not be diminished too much even in mines. It is the author's experience that as little as 19 per cent of oxygen is rarely found in the moving air of coal mines. However, at some of the working faces of poorly ventilated mines only 17 per cent of oxygen is found.

In mines other than coal mines, carbon dioxide is given off by the burning of lights, by the decay of mine timbers, and, in some mines, by the rocks penetrated. At poorly ventilated working places in some metal mines the carbon dioxide content may be dangerously high or the oxygen content dangerously low, or both conditions may prevail.

As indicated above, an oxygen content as low as 17 per cent is itself without harm, for people live at altitudes where the proportion of oxygen corresponds to this percentage at sea level. The air of many health resorts contains even less oxygen by weight than does the air of Denver, but the air at those resorts is fresh, moving, and invigorating, and usually rather dry. Mine air that contains so small a percentage of oxygen is in no sense comparable to the air of these health resorts. If the air in a part of a certain mine contains only 17 per cent by volume of oxygen not enough fresh air is finding access there; that is, the air is more or less stagnant, perhaps with all the attendant evils discussed previously.

The difference between ventilation conditions in buildings aboveground and in coal mines is in the degree of vitiation of the air as regards low oxygen and high carbon dioxide; aboveground relatively small oxygen and carbon dioxide changes—a few tenths of 1 per cent—usually represent bad air; belowground these small percentages are insignificant. In England, the law requires that the oxygen content shall not fall below 19 per cent or the carbon dioxide content rise above 1.25 per cent in any part of the mine.[a] Mines in this country can easily meet these requirements.

The amount of fresh air per man introduced into coal mines far exceeds that allotted by architects and engineers for ventilating public buildings. As a basis on which to calculate the air necessary for proper ventilation of public buildings, one may consider the carbon dioxide produced by an adult as 0.6 cubic foot per hour. Hence, in 6,000 cubic feet of air, he will produce per hour a pollution amounting to 1 part of carbon dioxide in 10,000 parts of air. If the excess of carbon dioxide were to be kept down to this figure it would be necessary to supply 6,000 cubic feet of fresh air per hour; if the permissible excess was to be 2 parts in 10,000, half this supply would suffice, and so on. The amount of fresh air allowed by ventilating engineers in this country varies from 1,800 cubic feet per hour per person for school buildings, auditoriums, theaters, factories, etc., to 12,000 cubic feet per hour per person in surgical and contagious hospitals.

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[a] Coal mines act, Great Britain, 1911.

In the nongaseous bituminous mines of Pennsylvania the minimum quantity of air per man is 150 cubic feet per minute, or 9,000 cubic feet per hour. In a mine where explosive gas is generated in dangerous quantities the minimum is 12,000 cubic feet per hour per man. These quantities exceed the quantity stipulated in the ventilation of large public halls. Consequently in the moving airways of such mines the air is fresh and wholesome. The temperature is seldom high, and usually bad ventilation exists only at some working faces where the air does not find ready access.

There has been considerable discussion regarding a scheme proposed in England to lower the oxygen content of the air in mines to a point (about 17 per cent) where the risk from explosion of mixtures of methane and air is reduced. Most mining men are opposed to such procedure on physiological grounds. The author's experience has indicated that the oxygen content has to be reduced below this figure to lessen appreciably the liability of gas explosions. (See pages 24–25.)

Some investigators have argued that disastrous coal-dust explosions of recent years can be attributed largely to the better ventilation of mines at present as compared with the ventilation found years ago. To make such a comparison just involves the consideration of too many factors to warrant discussion here. There is truth in the statement, at least as regards mixtures of methane and air, to the extent that greater violence is exerted by an explosive mixture if the latter has a high initial velocity of its own. The authors have seen this demonstrated many times in an explosion gallery of their own construction.[a] But an unbiased consideration of evidence accumulated through long experience must lead one to accept the necessity of plenty of fresh air. Whether for a miner working underground, a man at a health resort, or an assemblage in a large public building, all the fresh air that can reasonably be obtained is needed.

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[a] Details to be published later. The high initial velocities of the gallery tests are, however, probably almost unknown in mines where an explosive mixture of methane and air might exist.

ACTION OF OXYGEN ON COAL.

Many investigations have been made into the mode of absorption of oxygen by coal, which is of much practical importance, for this reaction is mainly responsible for the depletion of oxygen and increase of carbon dioxide in the atmosphere of a coal mine. The detrimental effect is that in some parts of mines atmospheres are produced so low in oxygen that they will not support the combustion of lights or that they impair the health of the miners. By sealing off affected areas, oxygen absorption by coal can be utilized to extinguish mine fires, to prevent spontaneous combustion, or to produce an atmosphere so low in oxygen that explosions of methane and air, or coal dust and air, can not occur.

The exact manner in which coal absorbs oxygen is not clearly understood. A solid substance can hold gases actually dissolved in its interior. With coal, the absorption of oxygen is complicated by the fact that, in addition to this physical action, there is also a very complex chemical action. Part of the oxygen is converted into water, part into carbon dioxide, and part is retained as combined oxygen, producing compounds richer in oxygen than the coal itself. Part of the carbon dioxide is retained by the coal, for coal at ordinary temperatures has an enormous capacity for holding carbon dioxide.

Many investigations have been made into the absorption and liberation of gases by coal, as is indicated by the following selected bibliography:

Selected bibliography on absorption and liberation of gases by coal.

Anderson, W. C. A contribution to the chemistry of coal, with special reference to the coals of the Clyde Basin. Phil. Soc. Glasgow, vol. 29, 1897, pp. 72–96.

Bedson, P. P. The gases inclosed in coal dust. Chem. News, vol. 68, 1893, p. 187.

Boudouard, M. O. Études sur les charbons, produits resultant de leur oxydation. Bull. Soc. chim. France, ser. 4, t. 5, 1909, pp. 377–380.

Chamberlain, R. T. Notes on explosive mine gases and dusts, with special reference to the explosions in the Monongah, Darr, and Naomi coal mines. Bull. 26, Bureau of Mines, p. 32 (reprint of U. S. Geol. Surv. Bull. 383).

Harger, John. The detection of gob fires. Trans. Inst. Min. Eng., vol. 46, 1913–14, p. 370.

Lamplough, F. E. E., and Hill, A. M. The slow combustion of coal and its thermal value. Trans. Inst. Min. Eng., vol. 45, 1913, p. 629.

Parr, S. W., and Wheeler, W. F. Year book of Illinois State Geological Survey. Ill. State Geol. Survey Bull. 8, 1907, p. 168.

Taffanel, J. De l'alteration des poussières de houille exposées a l'air. Original Communications, 8th Int. Cong. Appl. Chem., vol. 10, 1912, p. 277.

Threlfall, Richard. The spontaneous heating of coal, particularly during shipment. Jour. Soc. Chem. Ind., vol. 38, 1909, p. 759.

Trobridge, F. G. Gases inclosed in coal and certain coal dusts. Jour. Soc. Chem. Ind., vol. 25, 1906, p. 1129.

Recent investigations into the action of air on coal are those of Winmill and Graham.[a]

Winmill[b] determined that under his conditions of experiment there was little difference between the rates of oxidation by air, except for mother of coal and slate, between various parts of a seam of coal that he sampled. Hard coal, soft coal, cannel coal, jacks, shale, and mother of coal were tried. He also found that the amount of oxygen absorbed was roughly proportional to the amount of carbonaceous matter present in each substance. One hundred and fifty grams of 200-mesh coal absorbed 169 to 830 c. c. of oxygen at a temperature of 30° C. Winmill states that there are two factors in the oxidation of coal—a rapid first reaction, which is soon over, and a slow reaction, responsible for the major part of the oxygen absorption. He found, as have other investigators, that oxidation of coal, so rapid that the coal heats up, can take place in the absence of pyrites, only a small amount of carbon dioxide being produced. From the hard coal at 30° C. less than 20 c. c. of carbon dioxide was formed during the absorption of 20 c. c. of oxygen. A reduction of the proportion of oxygen to 8.28 per cent (not of the quantity of air) did not slow up the reaction very perceptibly.

With 100-mesh dust the rate of absorption was 72 per cent of that with 200-mesh dust. Increasing the temperature of the experiment from 40° to 60° C. practically doubled the rate of absorption. In another communication Winmill[c] gives the results of some experiments on the rate of absorption of carbon dioxide by coal. The temperature of the experiment was 30° C. The proportion of carbon dioxide absorbed by 100 grams of coal varied from 0.97 c. c., with 0.10 per cent of carbon dioxide in the atmosphere, up to 472 c. c., with an atmosphere containing 100 per cent of carbon dioxide.

INFLUENCE OF MOISTURE ON RATE OF ABSORPTION OF OXYGEN BY COAL.

Fayol[d] maintains that there is little evidence in support of the view that moisture accelerates the firing of coal heaps.

Richters[e] concludes that more oxygen is absorbed by dry than by moist coal.

Mahler[f] found that coal in the presence of oxygen under pressure absorbed a considerably larger quantity when moist than when dry.

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[a] Graham, J. I., The absorption of oxygen by coal: Trans. Inst. Min. Eng., vol. 59, Feb., 1915, p. 35.

[b] Winmill, T. F., The absorption of oxygen by coal: Trans. Inst. Min. Eng., vol. 46, 1913–14, pp. 563, 568.

[c] Winmill, T. F., Op. cit., vol. 48, Feb., 1915, p. 514.

[d] Threlfall, Richard, The spontaneous heating of coal, particularly during shipment: Jour. Soc. Chem. Ind., 1909, vol. 28, p. 763.

[e] Threlfall, Richard, Op. cit., p. 759.

[f] Mahler, M. P., Experiments on the oxidation of coal: Coll. Guard., 1913, vol. 106, p. 891.

Graham[a] determined that (1) at temperatures below 50° C. coal dust when moist absorbs oxygen at a rate approximately half as great again as when dry; (2) that coal dust heated for some hours at a temperature of 100° C. in a vacuum during subsequent oxidation absorbs oxygen at the same rate as when not previously heated; (3) that the absorption of oxygen by coal is independent of bacterial activity.

Porter and Ovitz[b] found that 10 kilograms of coal (22 pounds) in a bottle absorbed during the first day after mining nearly half the oxygen from 10 liters of air and gave off little more than one-tenth as much carbon dioxide as would have been formed if all the oxygen had combined with carbon to produce carbon dioxide. Four coals that Porter and Ovitz tested in bottles absorbed in 7, 9, 10, and 17 months 4.362, 2.853, 4.115, and 6.935 volumes of oxygen, as compared with the volumes of the coals. From time to time the gas that accumulated in each bottle was drawn off in order to relieve the pressure and permit the inflow of oxygen.

Porter and Ralston[c] found that with the same coal the rate of oxidation increased from 0.21 c. c. of oxygen absorbed per gram of dry coal at 40° C. to 27.68 c. c. absorbed at 200° C., the duration of each test being 60 minutes. They found that the oxygen content of the air must be reduced below 15 per cent, or to a pressure of about 100 mm. when pure oxygen is used, before the effect on the rate of oxidation becomes serious, and that the presence of as much as 10 per cent of carbon dioxide in the atmosphere has no retarding influence on the rate of oxidation at 200° C.

Winmill, it will be remembered, found that if the percentage of oxygen in air be reduced to 8.20 the reaction did not slow perceptibly, but his results are not in harmony with those of Porter and Ralston. It is certain, of course, that the rate of oxidation must eventually fall decidedly when the oxygen content of the air becomes low, and must be zero when the oxygen content of the atmosphere is zero.

ABSORPTION OF OXYGEN AND PRODUCTION OF CARBON DIOXIDE FROM ATMOSPHERIC AIR BY WOOD.

Many metal mines are heavily timbered and in some mines, especially in dead ends where the air is stagnant, the wood is moist, and much timber is present, the carbon dioxide content of the air is increased and the oxygen content is decreased.

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[a] Graham, J. I., The absorption of oxygen by coal: Trans. Inst. Min. Eng., vol. 59, Feb., 1915, p. 35.

[b] Porter, H. C., and Ovitz, F. K., The escape of gas from coal: Tech. Paper 2, Bureau of Mines, 1911, pp. 6–7.

[c] Porter, H. C., and Ralston, O. C., A study of the oxidation of coal: Tech. Paper 65, Bureau of Mines, 1914, p. 13.

Some results by the authors on the action of air on wood are given in Table 3 following. Dried and seasoned pieces of wood plank were sawed or shaved to produce sawdust or shavings. The material was placed in bottles having a capacity of 2.5 liters and the bottles were securely closed. Through each bottle stopper was placed a glass tube provided with a stopcock to permit drawing out samples of air for analysis.

Results of experiments to determine effect of wood in changing composition of atmospheric air.

Kind of wood.	Weight.	Constituent.	First analysis of residual air, June 27, 1913.	Second analysis of residual air, July 15, 1913.	Third analysis of residual air, July 31, 1913.[a]	Fourth analysis of residual air, Aug. 21, 1913.	Fifth analysis of residual air, Sept. 16, 1913.	Sixth analysis of residual air, Dec. 12, 1915.
	Grams.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Ash sawdust	5	CO_2	0.0	0.15	3.38	11.6	18.9	20.6
		O_2	20.8	20.8	17.50	8.6	1.7	.0
Cypress shavings	76	CO_2	.0	.15	1.98	4.0	6.0	10.0
		O_2	20.9	20.80	18.75	16.7	14.4	10.1
Hemlock sawdust	135.5	CO_2	.20	.20	7.87	16.6	18.0	17.7
		O_2	20.8	20.80	12.00	2.0	.7	.3
Oak sawdust	136	CO_2	.2	.2	8.27	17.0	19.2	20.2
		O_2	20.7	20.8	15.05	3.1	1.2	.4

[a] Water was added to each bottle 15 days after the tests were started and just prior to these analyses.

DISCUSSION OF RESULTS.

The experiments were started on June 6, 1913, and the first analyses of the residual air were made on June 27, 1913. No appreciable change in the oxygen or carbon dioxide content of the residual air over the composition of ordinary atmospheric air was noticed. The same statement held true of results obtained on July 15, 1913, or 39 days after the experiments were started. Water was then added to each bottle in sufficient quantity to perceptibly moisten the sawdust and shavings, and analyses were again made. After 16 days from the time the wood had been moistened, analyses were made of the residual air, and a marked increase in carbon dioxide and a marked decrease in oxygen were found. These changes continued in the sawdust samples until the oxygen had practically all disappeared. The rate of absorption of the oxygen by the fine cypress shavings was slower, probably owing to the fact that the cypress wood was not in as fine a state of division as the other woods tried.

An interesting feature of the results was that the carbon dioxide was only slightly less than the molecular equivalent of the oxygen consumed. This result differs from that obtained when oxygen is absorbed by coal at ordinary temperatures. The amount of carbon dioxide produced by coal is invariably less than the molecular equivalent of the consumed oxygen. In fact, the oxygen may entirely or almost entirely disappear, and there may be present in the residual air only 2 or 3 per cent of carbon dioxide. Bacterial action apparently does not enter into the phenomenon, whereas as regards the reaction between wood and oxygen, bacterial action is probably almost wholly responsible.

EFFECT OF LOWERING OXYGEN AND RAISING CARBON DIOXIDE CONTENT ON EXPLOSIBILITY OF METHANE-AIR MIXTURES.

In coal mines, especially if the air is not in rapid circulation, the composition of the atmosphere may change quickly. The principal changes that affect the explosibility of mine atmospheres are those caused by the absorption of oxygen by the coal and the oxidation of coal to carbon dioxide. Both of these changes if carried far enough can result in so lowering the oxygen content or raising the carbon dioxide content that an explosion can not take place even if an explosive proportion of methane is present. Therefore, knowledge of the propagation of flame in limit mixtures of methane, carbon dioxide, oxygen, and nitrogen is important.

Haldane[a] was the first to publish results of experiments bearing on this point. The composition of those mixtures containing the smallest percentages of oxygen that he found would completely inflame follows. Haldane presented his results in terms of black damp, fire damp, and air. In the following table his results have been recalculated to show the percentages of carbon dioxide, oxygen, methane, and nitrogen:

Inflammable mixtures containing small percentages of oxygen.

Mixture No.—	CO_2.	O_2.	CH_4.	N_2.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*
1	4.21	11.90	7.46	76.43
2	3.58	13.23	6.85	76.34
3	3.41	13.63	6.46	76.50

Haldane's experiments were made with gas obtained from a coal mine, which was passed into a cylinder, the size of a lamp chimney, from above. Ignition was effected by a small flame from below. Others who have worked on this phase of the subject have been Harger,[b] Leprince-Ringuet,[c] and Burgess and Wheeler,[d] but the most exhaustive experiments having to do with the explosibility of methane-air mixtures, in which part of the oxygen of the air was replaced by nitrogen or carbon dioxide or both, have been performed by Clement.[a]

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[a] Haldane, J. S., Investigations on the composition, occurrence, and properties of black damp: Trans. Inst. Min. Eng., vol. 8, 1894–95, pp. 549–567.

[b] Harger, John, The prevention of explosions in mines: Trans. Inst. Min. Eng., vol. 43, 1912, pp. 132, 136.

[c] Leprince-Ringuet, F., The inflammability of fire damp and other gases: Coll. Guard., vol. 108, Aug. 14, 1914, p. 376.

[d] Burgess, M. J., and Wheeler, R. V., The propagation of flame in limit mixtures of methane, oxygen, and nitrogen: Jour. Chem. Soc., vols. 105 and 106, November, 1914, pp. 2596–2605.

In Clement's first experiments the gases at atmospheric pressure were contained in a Hempel explosion pipette over mercury. The source of ignition, a spark from an induction coil, was applied near the top of the pipette.

Clement found that the limits of inflammability were narrowed as the oxygen was diminished until with 14 per cent of oxygen the low limit was 6.5 per cent of methane and the high limit 6.9 per cent. The inert gas present was nitrogen. When the oxygen was kept constant at 20 per cent and part of the nitrogen replaced by 10 per cent of carbon dioxide the low limit was raised from 5.8 per cent of methane to 6.2 per cent. When the oxygen was again constant at 20 per cent it required the replacement of part of the nitrogen by 62 per cent of carbon dioxide to raise the low limit to 8.8 per cent of methane. Clement found that even when the oxygen was reduced to 17 per cent there was no change in the inflammability of methane-air mixtures from the 5.8 per cent limit observed with 20 per cent of oxygen.

Another set of results was obtained by Clement with a steel tube closed at both ends to hold the mixtures. This tube was provided with stopcocks, an electric-arc igniter, a mixing device, a window for observing the flame, and an opening covered with a paraffin-paper diaphragm through which the pressure was released. The igniter was designed so that an arc could be maintained momentarily or for any desired time. The arc was connected to a 220-volt, direct-current circuit, with suitable resistances in series to give a current of 1.5 amperes, and was placed at the center of the vessel.

With this device the low limit of methane with 19 per cent of oxygen was 5.5 per cent, or 0.3 per cent lower than that found by the first method. With 17 per cent of oxygen the low limit was raised to 5.7 per cent, but even with 13 per cent of oxygen the mixture was explosive with a content of 6.6 per cent as the low limit and 6.8 per cent as the high limit. This second series of experiments again brought out the fact that a large proportion of carbon dioxide was necessary to appreciably affect the limits.

Clement concluded that the action of carbon dioxide in reducing the explosibility of methane-air mixtures can be accounted for by the high specific heat of this gas. He found that carbon dioxide was more effective than nitrogen in reducing explosibility.

The reader should note that atmospheres without enough oxygen (about 17 per cent) to support an oil-fed flame may be explosive if they contain enough methane. For instance, a miner may travel beyond a place where his flame goes out to a place where the methane is present in explosive proportion, and attempt to relight his lamp there. Its flicker just before it became extinguished would have ignited the mixture, were it explosive. Electric sparks in such an atmosphere would be another source of danger.

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[a] Clement, J. K., The influence of inert gases on inflammable gaseous mixtures: Tech. Paper 43, Bureau of Mines, 1913, 24 pp.

The limits of inflammability as determined by two of the authors for mixtures of methane and air in which the methane was simply added to the air were 5.5 per cent for the low limit and 14 per cent for the high limit.[a]

In metal mines, gases that make explosive mixtures with air are seldom found except as the result of a mine fire, but dangerous quantities of methane have been found in some metal-mining operations, as in a tunnel investigated by engineers of the Bureau of Mines.[b]

CONSUMPTION OF OXYGEN AND PRODUCTION OF CARBON DIOXIDE BY MEN AND BY LIGHTS.

A small proportion of the total carbon dioxide in the air of coal mines is that exhaled by men and given off by lights, and the diminution of oxygen is partly due to consumption of oxygen by these agencies. In a sample of air from an air current of a split where 37 men were working, the authors found by analysis 0.32 per cent CO_2, 20.47 per cent O_2, 0.13 per cent CH_4, and 79.08 per cent N_2. The quantity of air passing where the sample was collected was 15,000 cubic feet per minute. If one assumes that each man consumed one-seventh of a cubic foot of oxygen per minute and produced one-seventh of a cubic foot of carbon dioxide[c] during the same time, and that each light consumed about 0.03 cubic foot of oxygen per minute and produced the same quantity of carbon dioxide, there would have been consumed by the men and lights about 6.5 cubic feet of oxygen and they would have produced about 6.5 cubic feet of carbon dioxide. These figures represent only 0.04 per cent of the total oxygen consumed and of the total carbon dioxide produced and are practically negligible compared to the oxygen consumed and the carbon dioxide given off by the action of the oxygen of the air on the coal. Of course, if in this part of the mine, more men had been working, or if the quantity of air passing had been less, appreciable vitiation of air would have resulted from the breathing of the men or the burning of the lights.

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[a] Burrell, G. A., and Oberfell, G. G., The limits of inflammability of mixtures of methane and air: Tech. Paper 119, Bureau of Mines, 1915, pp. 25–26.

[b] Brunton, D. W., and Davis, J. A., Safety and efficiency in mine tunneling: Bull. 57, Bureau of Mines, 1914, pp. 29–30.

[c] Actually the oxygen absorbed exceeds in small amount the carbon dioxide discharged; the respiratory quotient, $\frac{CO_2}{O_2}$, being equal to about 0.90.

In most metal mines, lights and the breathing of men and of animals are more important in removing oxygen from and adding carbon dioxide to the mine air, because less oxygen is removed and less carbon dioxide is added in other ways.

FOULING OF MINE AIR BY DECAY OF TIMBER.

In all mines in which timber is used, some oxygen is taken from the air and some carbon dioxide is added to it by the decay of the timber. This source of black damp is much more important in many metal mines than in most coal mines because of the much larger quantity of timber used, especially in heavy ground. Timber decays through the action of various low forms of plant life, chiefly fungi, some of which take oxygen from the mine air, and practically all of which give off carbon dioxide.

SPECIFIC GRAVITY AND COMPOSITION OF BLACK DAMP.

The specific gravity of black damp varies considerably. When methane is present the combined gases may be lighter than air. Great caution should be exercised when any accumulation of black damp lighter than air is found, especially in mines worked with naked lights, as the lesser density is probably due to the presence of methane.

A sample of the following composition was collected by the authors from a cavity in a room of a coal mine:

Results of analysis of sample of mine air of much less density than atmospheric air.

CO_2	0.35
O_2	15.82
CH_4	19.32
N_2	64.51
	100.00

Owing to the large amount of methane present, the specific gravity (air = 1) of this sample was only 0.91.

The analysis of another sample showed an accumulation of methane and a deficiency of oxygen in an inclosed section of an anthracite mine that had been sealed for six days because of a fire in an adjoining section. The fire did not affect the particular area from which the sample was obtained because of a heavy intervening roof fall; consequently the sample represented the gases trapped in a stagnant section unaffected by fire. The results of analysis follow:

Results of analyses of samples of gas in an inclosed area of an anthracite mine.

CO_2	2.6
O_2	3.0
CH_4	53.0
N_2	41.4
	100.0

The specific gravity of this mixture (air = 1) was only 0.77, owing to the large proportion of methane.

Mixtures containing a large amount of carbon dioxide are often found on the floor and in low-lying workings. It happens occasionally that the gas is in a heavy stratum with lighter air above, and these strata are at times so sharply defined that a lighted candle is extinguished at once by lowering it only 1 inch below a certain level.

Equally distinct stratification of gases may be encountered in metal mines. A mixture containing more carbon dioxide, and being consequently heavier than normal air may lie near the floor, or a mixture containing less oxygen and more nitrogen, and being consequently lighter than normal air may accumulate near the roof or in a raise. Either the heavier or the lighter mixture, dangerous to the miner, may be so well stratified that a few inches will make the difference between breathable air and suffocating gases.

Before starting some work near the floor, a miner may hang his lamp well up in the roof, where by burning it indicates that the air near it is breathable; while the air near the floor may be so bad that it would extinguish the lamp immediately. However, except in air directly over a fire area or close to a fire, a large amount of carbon dioxide (over 5 per cent) is unusual in a coal mine. The small proportion of carbon dioxide normally in mine air is indicated by the many analyses of samples presented in this report. Exceptions are samples 5866, 5867, 5785, and 5786 (see p. 40), in which the carbon dioxide percentages were 14.42, 14.36, 19.60, and 19.33, and the specific gravities 1.051, 1.051, 1.071, and 1.069. The samples were collected from sealed mines in which there were or had been fires.

The authors' experience as a result of analyzing gas samples collected from many mines has indicated that if the carbon dioxide results from the action of the oxygen of the air on the coal (including perhaps a small amount released from the pores of the coal), it is not produced in proportions exceeding more than 3 to 5 per cent even after the air has long been in contact with the coal.

The following results of analyses show how small the carbon dioxide content may be in the air of a mine that has been sealed for nine months.

Results of analyses of gas samples from a mine area that had been sealed for nine months.

Sample No.	CO_2.	O_2.	CH_4.	N_2.	Total.	Specific gravity.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	
1	1.50	0.30	5.29	92.91	100.00	0.95
2	1.20	.30	5.37	93.13	100.00	.94

The collectors of the samples wore breathing apparatus. The oxygen had almost entirely disappeared, but only 1.20 and 1.50 per cent of carbon dioxide were present.

EFFECT ON LIGHTS OF AIR LOW IN OXYGEN AND HIGH IN CARBON DIOXIDE.

All mine air is somewhat deficient in oxygen as compared with outside air. This deficiency may amount to 0.1 to 2 per cent or more. As the oxygen in air decreases, the illuminating power of lights grows less; the flame of an ordinary oil-fed lamp wick becomes extinguished in air containing about 17 per cent of oxygen.

Haldane [a] determined the effect on the light of a safety lamp when burned in atmospheres deficient in oxygen. The following tabulation prepared by him is of exceptional interest.

Results of tests to determine diminution of light with diminution of oxygen in surrounding air.

Light given.	Proportion of oxygen in surrounding air.	Degree of light diminution.	Degree of oxygen diminution.
Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
100	20.93	0	0.00
90	20.66	10	0.27
77	20.34	23	0.59
66	19.88	34	1.05
41	19.34	59	1.89
27	18.92	73	2.01
11	18.28	89	2.65
0	18.01	100	2.92

Haldane observed, in general, that every diminution of 0.1 per cent in the oxygen content of the surrounding air caused a diminution of 3.5 per cent of the value of the light in pure air.

The results of some experiments by the authors with atmospheres that would extinguish a flame are shown below. Lighted candles and acetylene and Wolf lamps were placed in a chamber with air, and when the oxygen content had become so low that the flames were extinguished the residual air was analyzed.

Results of experiments with atmospheres that would extinguish flame.

Source of flame extinguished.	Analysis of residual air.		
	CO_2.	O_2.	N_2.
	Per cent.	*Per cent.*	*Per cent.*
Candle	2.95	16.24	80.81
Acetylene lamp	6.30	11.70	82.00
Wolf lamp	3.00	16.30	80.70

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[a] Haldane, J. S., The effects of deficiency of oxygen on the light of a safety lamp: Coll. Guard., vol. 106, Oct. 25, 1912, p. 836.

The carbon dioxide present, which was due to combustion, had no appreciable effect in extinguishing the flame, as was shown by certain experiments performed by the authors. In the experiments varying proportions of carbon dioxide were added to the atmosphere before the flame was introduced. The results of analyses made in connection with the experiments follow:

Results of experiments to determine effect of carbon dioxide in extinguishing the flame of a candle.

Experiment No.	Composition of atmosphere at beginning of experiment.		Composition of atmosphere at end of experiment.	
	CO_2.	O_2.	CO_2	O_2.
1	0.04	21.00	2.95	16.34
2	3.22	21.13	6.51	16.68
3	13.52	20.67	16.00	17.39

The results show that the initial presence of a large amount of carbon dioxide had little effect in extinguishing flame. In all of the laboratory experiments the flame probably lasted a trifle longer than it would have in actual mining practice, because in mines a slight gust of air or a quick movement of a lamp would easily put out a diminishing flame.

For the experiments a certain atmosphere was prepared in a 10-liter bell jar, and the flame was allowed to burn in it until the oxygen had been consumed to a point where the flame would no longer burn. Incidentally there was formed by the combustion a certain amount of carbon dioxide, but the amounts formed had no appreciable effect in extinguishing the flame.

Other experiments to determine the amount of carbon dioxide required to appreciably affect flame extinguishment were made, as follows:

Various mixtures of air and carbon dioxide were prepared in a large 100-liter gas holder, and these mixtures were slowly passed into and out of a small bell jar in which was burning a Wolf miner's safety lamp. The different atmospheres were kept as near constant at 17, 18, 19, 20, and 21 per cent of oxygen as possible, and to each of the mixtures carbon dioxide was added (replacing some nitrogen) until enough carbon dioxide was present to extinguish the flame at the particular oxygen percentage used.

The experiments show simply the effect on flame extinguishment of replacing an equivalent amount of nitrogen with carbon dioxide. Carbon dioxide should have a greater extinguishing power than nitrogen, because of its greater molecular specific heat and its greater conductivity of heat. The percentages of carbon dioxide and of oxygen in the different mixtures that extinguished flame are shown in the following tabulation.

Percentages of carbon dioxide and of oxygen in different mixtures of the two that extinguished flame.

CO_2.	O_2.	CO_2.	O_2.
0	16.3	25	18.7
5	16.9	30	19.2
10	17.3	35	19.6
15	17.8	40	20.3
20	18.3	43	21.0

It will be observed that a large percentage of carbon dioxide (replacing the nitrogen) was required to extinguish the flame, 5 per cent of carbon dioxide raising the oxygen content of the extinguishing mixture from 16.3 to 16.9 per cent. This proportion of carbon dioxide in mine air when the oxygen has fallen to 16 or 17 per cent is unusual. It can be said for all practical purposes that the carbon dioxide in mine air has no effect in extinguishing the lamp flames.

Jorrisen [a] has made experiments and compiled data from various sources on flame extinguishment, as shown below:

Results of Jorrisen's experiments with flame-extinguishing atmospheres.

Kind of flame.	Proportions in natural extinguishing atmosphere.		Proportions in artificial extinguishing atmosphere.		
	O_2	N_2	CO_2 added.	O_2	N_2
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Candle	16.4	83.6	14	18.1	81.9
Hydrogen	6.3	93.7	58	8.8	91.2
Carbon monoxide	15.1	84.9	24	16.0	84.0
Methane	17.4	82.6	10	18.9	81.1
Ethylene	13.2	86.8	26	15.5	84.5
Petroleum	16.2	83.8	15	17.9	82.1
Ethyl alcohol	16.6	83.4	14	18.1	81.9
Methylated spirits	17.2	82.8	13	18.3	81.7
Coal gas	11.3	88.7	33	14.1	85.9
Flax	16.0	84.0			

The results of experiments of other investigators, as compiled by Jorrisen, follow:

Results of experiments of various investigators on flame-extinguishing atmospheres.

Nature of flame.	Investigator.	Residual atmosphere.		
		O_2	N_2	CO_2
		Per cent.	*Per cent.*	*Per cent.*
Candle	Clowes	15.70	81.10	3.20
Do	Burrell	16.24	80.81	2.95
Soft candle	Harger	16.90		
Kerosene	Clowes	16.60	80.40	3.00
Do	Harger	16.90		
Petrol spirit	do	16.90		
Gasoline	do	15.50		
Alcohol	Clowes	14.90	80.75	4.35
Methylated spirit	do	15.60	80.25	4.15
Coal gas	do	11.35	83.75	4.90
Natural gas	Burrell	13.90	82.85	3.25
Hydrogen	Clowes	5.50	94.50	
Do	Harger	7.50		
Carbon monoxide	Clowes	13.35	74.40	12.25
Methane	do	15.60	82.10	2.30
Acetylene	Burrell	11.70	82.00	6.30

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[a] Jorrisen, W. P. The extinction of flames: Jour. Gas Lighting and Water Supply, vol. 130, Apr. 6, 1915, p. 27.

The agreement of most of the results is fairly satisfactory. The experiments are easy to perform, the principal source of error being insufficient mixing of the atmosphere, with its changing CO_2 and O_2 content, in which the flame is burning, and consequent nonrepresentative sampling.

Jorrisen calls attention to the fact that there is close similarity between the extinguishment of a flame, such as a burning candle or gas jet, in air as the oxygen decreases and the lessening explosibility of gas mixtures as the oxygen diminishes. If the composition of the air surrounding a burning gas jet is near the extinguishing limit, the temperature of the flame is almost instantly lowered so much that the combustible gas supplied can not be ignited, and the flame goes out. Similarly with explosive mixtures of gas and air in a globe, say, when the upper limit of explosion has been exceeded, the oxygen content has become so small that the flame can not extend itself beyond the source of ignition; that is, the mixture will not explode. This is shown in the following table:

Data showing relation between oxygen content of upper explosive limits of mixtures of certain gases and air and oxygen content of similar mixtures that will extinguish flame.

Gas.	Proportion of gas in upper explosive limit.[a]	Proportion of oxygen in gas mixture that extinguishes flame.	Proportion of oxygen at highest explosive limit.
		Per cent.	*Per cent.*
Hydrogen	65	6.50	7.3
Carbon monoxide	74	13.4	5.4
Methane	14.8	17.4	17.8
Gasoline vapor	6.0	15.5	19.6
Natural gas	12.0	13.90	18.4
Acetylene	75	11.70	5.23
Ethylene	22	13.2	16.3

[a] The values in this column were determined by the authors.

The comparison fails badly in the case of carbon monoxide and acetylene.

EFFECT OF ATMOSPHERES LOW IN OXYGEN ON FIRES IN MINES.

The effect of the oxygen content of mine air on a fire in a mine is important[a] and is as follows: When a burning section of a mine has been successfully sealed the atmosphere within changes in composition. It first loses oxygen until the content becomes so low, probably about 17 per cent, that flame can not exist. Eventually the oxygen content becomes so small that the rate of combustion slowly decreases, until ultimately the fire is out and the mine can be safely opened. Conclusions as to the approximate length of time a sealed mine, or part of a mine, should remain closed after a fire has been brought under control are hard to reach, because conditions differ greatly. When the oxygen in an area has been almost or entirely consumed combustion must necessarily stop, and the question then is how long the embers, or partly burned coal, can retain heat sufficient to permit rekindling on the admission of air. Systematic sampling and analysis of the atmosphere in different parts of a sealed mine will show whether the oxygen diminishes regularly, as it should if stoppings are tightly built, or whether air is leaking into the fire area.

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[a] See Burrell, G. A., and Seibert, F. M., Gas analysis as an aid in fighting mine fires: Tech. Paper 13, Bureau of Mines, 1912, 16 pp.; Burrell, G. A., and Oberfell, G. G., Explosibility of gases from mine fires: Tech. Paper 134, Bureau of Mines, 1916, 31 pp.; Rice, G. S., Mine fires, a preliminary study: Tech. Paper 24, Bureau of Mines, 1912, p. 38.

RESULTS OF ANALYSES OF COAL-MINE ATMOSPHERES.

In the course of the investigations reported in this bulletin a large number of analyses of mine atmospheres were made. Methods of analysis are given in Bulletin 42 of the Bureau of Mines.[a] The analyses were classified in series from 1 to 6, and, for convenience of reference, the original classification has been retained in presenting the results.

The following analysis of pure outside air is presented for comparison with the composition of the mine-air samples analyzed.

Analysis of pure air.

	Per cent.
Carbon dioxide (CO_2)	0. 03
Oxygen (O_2)	20. 93
Nitrogen (N_2)	79. 04
	100. 00

Included in the nitrogen percentage are the so-called rare gases of the atmosphere—argon, helium, neon, krypton, and zenon. These gases constitute about 1 per cent of the total constituents of air and, like nitrogen, are inert.

In the tabulations that follow, the carbon dioxide, oxygen, methane, and nitrogen, as found by analysis, are given. The results of analyses have been recalculated to show the air, black damp, and methane present and the percentage composition of the black damp. The air content is equal to the nitrogen equivalent of the oxygen, according to the proportions found in pure air plus 0.03 per cent of carbon dioxide. The black damp is equal to the total nitrogen minus the nitrogen equivalent of the oxygen plus the carbon dioxide in the mine air in excess of the amount (0.03 per cent) found in pure air.

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[a] Burrell, G. A., and Seibert, F. M., The sampling and examination of mine gases and natural gas: Bull. 42, Bureau of Mines, 1913, 116 pp.

The recalculation of the analysis of a mine-air sample will make clear the foregoing statement. The results of analysis of a mine-air sample follow:

Results of analysis of a sample of air from a coal mine.

	Per cent.
CO_2	0. 22
O_2	20. 13
CH_4	1. 57
N_2	78. 08
	100. 00

The above results recalculated to show air, black damp, and methane, would give results as follows:

Results of analysis of mine-air sample recalculated to show air, black damp, and methane.

	Per cent.	Per cent.
Air:		
CO_2	0. 03	
O_2	20. 13	
N_2	76. 01	
		96. 17
Black damp:		
CO_2	. 19	
N_2	2. 07	
		2. 26
Methane	1. 57	
		1. 57
		100. 00

The composition of the black damp would then be as follows:

CO_2	Per cent	8. 41
N_2	do	91. 59
		100. 00

The air in the above results is found as follows:

$$\text{Nitrogen equivalent of the oxygen}=\left(\frac{79.04}{20.93}\right)20.13=76.01$$

$$\text{Air}=76.01+20.13+0.03=96.17$$

The black damp in the above results is found as follows: The nitrogen in the sample in excess of that found in pure air $=78.08-76.01=2.07$ per cent. The carbon dioxide in the sample in excess of that found in pure air $=0.22$ per cent -0.03 per cent $=0.19$ per cent. The black damp $=0.19+2.07=2.26$ per cent.

RESULTS OF ANALYSES OF SAMPLES IN SERIES 1.

The results of analyses of samples included in series 1 are presented in the following table.

TABLE 4.—*Results of analyses*

Laboratory No.	Source of sample.		Remarks.	Laboratory analysis.			
	Mine No.	Point in mine.		CO_2.	O_2.	CH_4.	N_2.
				Per ct.	*Per ct.*	*Per ct.*	*Per ct.*
3734	1	20 feet from face of No. 8 east entry.	Air still; 1-inch cap on safety lamp.	0.35	19.89	1.94	77.82
3735	1	Face of No. 7 south entry..	Trace of methane shown by safety lamp.	.17	20.34	1.05	78.44
3771	2	Crosscut between 2 rooms.	Quantity of air, 4,200 cubic feet per minute; temperature, 61° F., W. B., 60° F., D. B.; relative humidity, 94 per cent.	.08	20.71	.37	78.84
3773	2	.....do....................	.....do....................	.11	20.64	.23	79.02
3934	3	([a])........................	([a])........................	7.41	5.76	2.93	83.90
3935	3	([a])........................	([a])........................	7.51	6.20	2.20	84.09
3981	4	No. 1 room, off No. 10 entry, at roof, 20 feet inby.	Air still..................	1.39	16.79	.07	81.75
3982	4	No. 1 room, off No. 10 entry, at floor, 10 feet inby.	.....do....................	1.17	18.39	.03	80.41
4001	5	Surface crack..............	Crack was over a sealed area in a drift mine that had been on fire a short time previous; fire probably out.	4.82	14.37	.56	80.25
4003	5	Room, 20 feet from a butt, 10 feet from floor.	.....do....................	7.83	10.69	.89	80.59
4071	6	Main intake for booster fan	....	.35	20.40	.00	79.25
4072	6	Heading of north entry, off 3 east.	....	.48	20.02	.02	79.48
4073	6	16 east, between rooms 56 and 57.	....	.53	20.10	.07	79.30
4074	6	Last crosscut between rooms 19 and 20, No. 16 east entry.	....	1.21	19.39	.07	79.33
4075	6	Main return, at upcast shaft.	....	1.00	19.31	.05	79.64
4008	7	Sixth left entry at face....	9,900 cubic feet of air per minute.	.09	20.44	1.95	77.52
4009	7	Return air course, near exhaust fan.	23,100 cubic feet of air per minute.	.16	20.63	.42	78.79
3339	8	20 feet inside brattice inclosing former fire area.	....	6.02	6.02	[b] .16 3.79	84.01
3340	8	80 feet inside brattice inclosing former fire area.	....	7.74	3.18	[b] .05 3.86	85.17
4138	9	Return air course..........	....	.19	20.61	.00	79.20
4135	9	.....do....................	....	.21	20.52	.00	79.27
5607	10	Main return................	27,000 cubic feet of air per minute; temperature 67° F., W. B. and D. B.; relative humidity, 100 per cent.	.31	20.46	.15	79.08
5609	10	Point in entry where air was considerably diluted with return air from fire area.	....	3.07	16.40	2.87	77.66
5602	11	Point in a room where it holed through into a manway.	6,900 cubic feet of air per minute; temperature, 76.5° F., W. B., 78° F., D. B.; relative humidity, 92 per cent.	1.53	18.84	2.16	77.47
5603	11	Manway.....................	6,900 cubic feet of air per minute; temperature, 74.5° F., W. B., 77.5° F., D. B.; relative humidity, 87 per cent.	.95	19.89	.66	78.50
5604	11	.....do....................	7,200 cubic feet of air per minute; temperature, 74.25° F., W. B., 77.25° F., D. B.; relative humidity, 87 per cent.	1.06	19.73	.80	78.41

[a] Sample was collected at the top of a bore hole through which mine air was issuing. The mine was a drift mine that had been sealed for 30 days because of fire. There were, however, many small openings in the outcrop, making impossible complete exclusion of air.

of coal-mine air samples, series 1.

Recalculated analysis, showing air, black damp, and methane.						Calculated composition of black damp.		Specific gravity of sample (air=1).
Air.			Black damp.		CH_4	CO_2.	N_2.	
CO_2.	O_2.	N_2.	CO_2.	N_2.				
Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
0.03	19.89	75.11	0.32	2.71	1.94	10.56	89.44	0.99
.03	20.34	76.81	.14	1.63	1.05	7.91	92.09	.99
.03	20.71	78.21	.05	.63	.37	7.35	92.65	.99
.03	20.64	77.94	.08	1.08	.23	6.90	93.10	1.00
.01	5.76	21.75	7.40	62.15	2.93	10.64	89.36	1.00
.01	6.20	23.41	7.50	60.68	2.20	11.00	89.00	1.01
.02	16.79	63.41	1.37	18.34	.07	6.95	93.05	1.00
.03	18.39	69.45	1.14	10.96	.03	9.42	90.58	1.00
.02	14.37	54.27	4.80	25.98	.56	15.59	84.41	1.01
.02	10.69	40.37	7.81	40.22	.89	16.26	83.74	1.02
.03	20.40	77.04	.32	2.21	.00	12.65	87.35	1.00
.03	20.02	75.60	.45	3.88	.02	10.39	89.61	1.00
.03	20.10	75.91	.50	3.39	.07	12.85	87.15	1.00
.03	19.39	73.22	1.18	6.11	.07	16.19	83.81	1.00
.03	19.31	72.92	.97	6.72	.05	12.61	87.39	1.00
.03	20.44	77.19	.06	.33	1.95	15.38	84.62	.99
.03	20.63	77.91	.13	.88	.42	12.87	87.13	1.00
.01	6.02	22.73	6.01	61.28	[b] .16 3.79	8.93	91.07	.99
.00	3.18	12.01	7.74	73.16	[b] .05 3.86	9.57	90.43	1.00
.03	20.61	77.83	.16	1.37	.00	10.46	89.54	1.00
.03	20.52	77.49	.18	1.78	.00	9.18	90.82	1.00
.03	20.46	77.27	.28	1.81	.15	13.40	86.60	1.00
.02	16.40	61.93	3.05	15.73	2.87	16.24	83.76	1.00
.03	18.84	71.15	1.50	6.32	2.16	19.18	80.82	.99
.03	19.89	75.11	.92	3.39	.66	21.35	78.65	1.00
.03	19.73	74.51	1.03	3.90	.80	20.89	79.11	1.00

[b] Laboratory analysis, CO.

TABLE 4.—*Results of analyses*

Laboratory No.	Source of sample.		Remarks.	Laboratory analysis.			
	Mine No.	Point in mine.		CO_2.	O_2.	CH_4.	N_2.
				Per ct.	*Per ct.*	*Per ct.*	*Per ct.*
5597	12	Main north return	15,600 cubic feet of air per minute; temperature, 66° F., W. B., and D. B.; relative humidity, 100 per cent.	.34	20.40	.23	79.03
5598	12	.....do	.....do	.31	20.42	.19	79.08
5599	12	Return of 14 north entry	4,040 cubic feet of air per minute; temperature, 67° F., W. B. and D. B.; relative humidity, 100 per cent.	.12	20.66	.22	79.00
5600	12	.....do	.....do	.15	20.68	.17	79.00
5578	13	Entry, at face	Temperature, 81.75° F., W. B., 82.75° F., D. B.; relative humidity, 92 per cent.	.35	20.18	1.25	78.22
5579	13	Seventh south entry, 25 feet from face.	6,000 cubic feet of air per minute.	.29	20.25	1.94	77.52
5580	13	Main south return	8,398 cubic feet of air per minute; temperature, 78.25° F., W. B., 79.25° F., D. B.; relative humidity, 96 per cent.	.33	20.20	1.42	78.05
5581	13	Last crosscut of fifth north entry.	3,780 cubic feet of air per minute; temperature, 81° F., W. B., 83° F., D. B.; relative humidity, 88 per cent.	.35	20.30	1.08	78.27
5583	13	Return at bottom of air shaft.	45,000 cubic feet of air per minute; 76.50° F., W. B., 77.50° F., D. B.; relative humidity, 96 per cent.	.36	20.37	.78	78.49
5586	13	South side return, 100 feet from air shaft.	5,880 cubic feet of air per minute; 78.25° F., W. B., 78.75° F., D. B.; relative humidity, 98 per cent.	.37	20.21	1.56	77.86
5587	13	Main north return, 100 feet from air shaft.	21,250 cubic feet of air per minute; 76.75° F., W. B., 78° F., D. B.; relative humidity, 99 per cent.	.28	20.41	.67	78.64
5499	14	100 feet outby eighth and ninth right.	Sample represented return air from eighth, ninth, tenth, and eleventh right, off north haulage; 2,000 cubic feet of air per minute; 67° F., W. B.; 68° F., D. B.; relative humidity, 95 per cent.	.08	20.44	.95	78.53
5500	14	.....do	.....do	.12	20.38	1.03	78.47
5501	14	Between eighth and ninth right in last breakthrough.	Air still	.10	20.18	2.04	77.68
5502	14	.....do	.....do	.16	19.57	4.56	75.71
5503	14	Ninth left, off north haulage, 100 feet from entrance.	Sample of return air from ninth, tenth, eleventh, and twelfth entries, off north haulage; 2,000 cubic feet of air per minute; 67° F., W. B. and D. B.; relative humidity, 100 per cent.	.09	20.39	1.19	78.33
5504	14	.....do	.....do	.12	20.38	1.03	78.47
5429	15	Third level, close to bulkhead on east side.	Metal mine; 62° F., W. B., 63° F., D. B.; relative humidity, 95 per cent.	.26	20.47	.00	79.27
5430	15	.....do	.....do	.25	20.44	.00	79.31
5431	15	Seventh level, west, at bulkhead.		.41	20.35	.00	79.24
5432	15	.....do		.27	20.53	.00	79.20
5433	15	Upcast shaft, 10 feet below collar.	10,000 cubic feet of air per minute.	.26	20.61	.00	79.13
5434	15	.....do	.....do	.27	20.60	.00	79.13

of coal-mine air samples, series 1—Continued.

Recalculated analysis, showing air, black damp, and methane.						Calculated composition of black damp.		Specific gravity of sample (air=1).
Air.			Black damp.		CH_4.	CO_2.	N_2.	
CO_2.	O_2.	N_2.	CO_2.	N_2.				
Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
0.03	20.40	77.04	0.31	1.99	0.23	13.48	86.52	1.00
.03	20.42	77.11	.28	1.97	.19	12.44	87.56	1.00
.03	20.66	78.02	.09	.98	.22	8.41	91.59	1.00
.03	20.68	78.10	.12	.90	.17	11.76	88.24	1.00
.03	20.18	76.21	.32	2.01	1.25	13.73	86.27	.99
.03	20.25	76.47	.26	1.05	1.94	19.85	80.15	.99
.03	20.20	76.28	.30	1.77	1.42	14.49	85.51	.99
.03	20.30	76.66	.32	1.61	1.08	16.58	83.42	.99
.03	20.37	76.93	.33	1.56	.78	17.46	82.54	.99
.03	20.21	76.32	.34	1.54	1.56	18.09	81.91	.99
.03	20.41	77.08	.25	1.56	.67	13.81	86.19	.99
.03	20.44	77.19	.05	1.34	.95	3.60	96.40	.99
.03	20.38	76.96	.09	1.51	1.03	5.62	94.38	.99
.03	20.18	76.21	.07	1.47	2.04	4.55	95.45	.99
.03	19.57	73.90	.13	1.81	4.56	6.70	93.30	.98
.03	20.39	77.00	.06	1.33	1.19	4.32	95.68	.99
.03	20.38	76.96	.09	1.51	1.03	5.62	94.38	.99
.03	20.47	77.30	.23	1.97	.00	10.45	89.55	1.00
.03	20.44	77.19	.22	2.12	.00	9.40	90.60	1.00
.03	20.35	76.85	.38	2.39	.00	13.72	86.28	1.00
.03	20.53	77.53	.24	1.67	.00	12.57	87.43	1.00
.03	20.61	77.83	.23	1.30	.00	15.03	84.97	1.00
.03	20.60	77.79	.24	1.34	.00	15.19	84.81	1.00

TABLE 4.—*Results of analyses*

Laboratory No.	Source of sample.		Remarks.	Laboratory analysis.			
	Mine No.	Point in mine.		CO_2.	O_2.	CH_4.	N_2.
				Per ct.	*Per ct.*	*Per ct.*	*Per ct.*
5075	16	20 feet from face and 20 feet east of room neck, 600 feet west of shaft bottom.	Sample taken in area where pillars were being split; air still.	2.68	13.70	.00	83.62
5076	16	.....do	.....do	2.66	13.74	.00	83.60
5077	16	Main return air course near shaft.	4,700 cubic feet of air per minute.	1.28	17.70	.00	81.02
5078	16	.....do	.....do	1.26	17.77	.00	80.97
5486	17	Manway, 6 feet inby	2,100 cubic feet of air per minute; 76° F., W. B., 79° F., D. B.; relative humidity, 87 per cent.	1.36	18.85	2.08	77.71
5487	17	.....do	.....do	1.41	18.87	2.06	77.66
5490	17	Manway, 200 feet inby	2,100 cubic feet of air per minute; 76° F., W. B., 79° F., D. B.; relative humidity, 87 per cent.	1.37	18.84	2.10	77.69
5491	17	.....do	.....do	1.39	18.86	2.08	77.67
5492	18	North haulage return	54,720 cubic feet of air per minute; 66.5° F., W. B., 66.5° F., D. B., relative humidity, 100 per cent.	.08	20.69	.34	78.89
5493	18	.....do	.....do	.08	20.70	.33	78.89
5465	19	Head of air course	1,900 cubic feet of air per minute.	1.31	18.42	2.09	78.18
5466	19	.....do	.....do	.38	20.30	.53	78.79
5467	19	Main return, inby foot of air shaft.	29,500 cubic feet of air per minute; 75.5° F., W. B., 77.75° F., D. B.; relative humidity, 89 per cent.	1.34	18.92	2.06	77.68
5468	19	.....do	.....do	.42	20.20	.50	78.88
5469	19	15 feet inby F entry	22,500 cubic feet of air per minute; 75.5° F., W. B., 77.75° F., D. B.; relative humidity 90 per cent.	.31	20.44	.48	78.77
5470	19	.....do	.....do	1.31	18.40	1.91	78.38
5472	19	.....do	.....do	1.35	18.66	2.04	77.95
4670	20	No. 1 room, 19th right entry, 4 feet from face and 18 inches from roof.	77° F., W. B. and D. B.; relative humidity 100 per cent.	.10	16.36	5.70	77.84
4671	20	.....do	.....do	.17	16.45	6.38	77.00
4674	20	Main return, 200 feet from pit mouth.	32,277 cubic feet of air per minute; 53.5° F., W. B. and D. B.; relative humidity 100 per cent.	.24	20.44	.14	79.18
4675	20	.....do	.....do	.27	20.45	.13	79.15
4556	21	Return air from 8th and 9th right entries.	66° F., W. B. and D. B.; relative humidity 100 per cent.	.08	20.68	.08	79.16
4557	21	.....do	.....do	.08	20.63	.06	79.23
4558	21	Return air from 8th left entry.	1,000 cubic feet of air per minute; 69° F., W. B. and D. B.; relative humidity 100 per cent.	.09	20.61	.08	79.22
4559	21	.....do	.....do	.09	20.67	.07	79.17
4509	22	Second crosscut, between rooms 1 and 2, 9th right.	Still air; 65° F., W. B., 66° F., D. B.; relative humidity, 95 per cent.	.21	18.94	6.43	74.42
4510	22	.....do	.....do	.21	19.07	6.62	74.10
5903	23	Return of one of two splits, 1,500 feet from pit mouth.	40,100 cubic feet of air per minute; 55° F., W. B., 56° F., D. B.	.05	20.85	.00	79.10
5904	23	.....do	.....do	.08	20.83	.02	79.07
5907	24	Main haulage way, 200 feet from portal.	35,100 cubic feet per minute; 55° F., W. B., 56° F., D. B.; relative humidity, 94 per cent.	.22	20.60	.04	79.14
5908	24	.....do	.....do	.25	20.57	.01	79.17

of coal-mine air samples, series 1—Continued.

Recalculated analysis, showing air, black damp, and methane.						Calculated composition of black damp.		Specific gravity of sample (air=1).
Air.			Black damp.		CH₄.	CO₂.	N₂.	
CO₂.	O₂.	N₂.	CO₂.	N₂.				
Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
0.02	13.70	51.74	02.66	31.88	0.00	7.70	92.30	1.00
.02	13.74	51.89	2.64	31.71	.00	7.69	92.31	1.00
.03	17.70	66.84	1.25	14.18	.00	8.10	91.90	1.00
.03	17.77	67.11	1.23	13.86	.00	8.15	91.85	1.00
.03	18.85	71.19	1.33	6.52	2.08	16.94	83.06	.99
.03	18.87	71.26	1.38	6.40	2.06	17.74	82.26	.99
.03	18.84	71.15	1.34	6.54	2.10	17.01	82.99	.99
.03	18.86	71.22	1.36	6.45	2.08	17.41	82.59	.99
.03	20.69	78.13	.05	.76	.34	6.17	93.83	1.00
.03	20.70	78.17	.05	.72	.33	6.49	93.51	1.00
.03	18.42	69.56	1.28	8.62	2.09	17.37	82.63	.99
.03	20.30	76.66	.35	2.13	.53	13.04	86.96	1.00
.03	18.92	71.45	1.31	6.23	2.06	12.93	87.07	.99
.03	20.20	76.28	.39	2.60	.50	14.11	85.89	1.00
.03	20.44	77.19	.28	1.58	.48	15.05	84.95	1.00
.03	18.40	69.49	1.28	8.89	1.91	12.59	87.41	.99
.03	18.66	70.47	1.32	7.48	2.04	15.00	85.00	.99
.02	16.36	61.78	.08	16.06	5.70	.50	99.50	.97
.02	16.45	62.12	.15	14.88	6.38	1.00	99.00	.97
.03	20.44	77.19	.21	1.99	.14	9.55	90.45	.97
.03	20.45	77.23	.24	1.92	.13	11.11	88.89	1.00
.03	20.68	78.10	.05	1.06	.08	4.50	95.50	1.00
.03	20.63	77.91	.05	1.32	.06	3.65	96.35	1.00
.03	20.61	77.83	.06	1.39	.08	4.14	95.86	1.00
.03	20.67	78.06	.06	1.11	.07	5.13	94.87	1.00
.03	18.94	71.53	.18	2.89	6.43	5.86	94.14	.97
.03	19.07	72.02	.18	2.08	6.62	7.96	92.04	.97
.03	20.85	78.74	.02	.36	.00	5.26	94.74	.99
.03	20.83	78.66	.05	.41	.02	10.87	89.13	.99
.03	20.60	77.79	.19	1.35	.04	12.34	87.66	.997
.03	20.57	77.68	.22	1.49	.01	12.87	87.13	.997

TABLE 4.—*Results of analyses*

Laboratory No.	Source of sample.		Remarks.	Laboratory analysis.			
	Mine No.	Point in mine.		CO_2.	O_2.	CH_4.	N_2.
				Per ct.	*Per ct.*	*Per ct.*	*Per ct.*
5866	25	Air-course entry	Mine sealed when sample was collected because of a previous mine fire.	14.42	3.42	[a] .41	81.42
5867	25	do	do	14.36	3.63	[a] .44	81.24
5785	25	Fire area in sealed mine, through hole in stopping of outcrop opening.		19.60	.90	[b] 1.95	77.45
5786	25	do		19.33	1.18	[b] 1.99	77.40
5818	26	Main return, 75 feet from mine mouth.	45,024 cubic feet of air per minute; 52° F., W. B., 52.5° F., D. B.; relative humidity, 97 per cent.	.07	20.67	.01	79.25
5819	26	do	do	.09	20.57	.04	79.30
5822	27	Face of right entry, 1,200 feet west of shaft.	3,600 cubic feet of air per minute; 53° F., W. B., 54° F., D. B.; relative humidity, 94 per cent.	.05	20.53	1.70	77.72
5823	27	do	do	.08	20.50	1.66	77.76
5730	28	Mouth of 7th butt entry	9,800 cubic feet of air per minute; 55° F., W. B. and D. B.; relative humidity, 100 per cent.	.12	20.60	.05	79.23
5731	28	do	do	.13	20.64	.04	79.19
5732	28	Manway, 300 feet southwest of pit mouth.	40,500 cubic feet of air per minute; 52.5° F., W. B., 53° F., D. B.; relative humidity, 97 per cent.	.07	20.74	.05	79.14
5733	28	do	do	.09	20.69	.05	79.17
5656	29	Main return, 10 feet from bottom of air shaft.	11,300 cubic feet of air per minute; 66° F., W. B., 67° F., D. B.; relative humidity, 95 per cent.	.71	19.85	.40	79.04
5657	29	do	do	.72	19.87	.43	78.98
5658	29	8½ east entry, at head of last room through from 9 east entry.	1,200 cubic feet of air per minute; 75° F., W. B., 76° F., D. B.; relative humidity, 96 per cent.	1.80	18.16	1.99	78.05
5659	29	do	do	2.00	17.78	2.21	78.01

[a] CO, 0.33 per cent.

[b] CO, 0.10 per cent.

of coal-mine air samples, series 1—Continued.

Recalculated analysis, showing air, black damp, and methane.						Calculated composition of black damp.		Specific gravity of sample (air=1).
Air.			Black damp.		CH$_4$.	CO$_2$.	N$_2$.	
CO$_2$.	O$_2$.	N$_2$.	CO$_2$.	N$_2$.				
Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
0.00	3.42	12.92	14.42	68.50	[c]0.33 .41	17.39	82.61	1.051
.01	3.63	13.71	14.35	67.53	[c].33 .44	17.53	82.47	1.051
.00	.90	3.40	19.60	74.05	[c].10 1.95	20.93	79.07	1.071
.00	1.18	4.46	19.33	72.94	[c].10 1.99	20.95	79.05	1.069
.03	20.67	78.06	.04	1.19	.01	3.25	96.75	.996
.03	20.57	77.68	.06	1.62	.04	3.57	96.43	.996
.03	20.53	77.53	.02	.19	1.70	9.52	90.48	.989
.03	20.50	77.42	.05	.34	1.66	12.82	87.18	.989
.03	20.60	77.79	.09	1.44	.05	5.88	94.12	.996
.03	20.64	77.94	.10	1.25	.04	7.41	92.59	.994
.03	20.74	78.32	.04	.82	.05	4.65	95.35	.996
.03	20.69	78.13	.06	1.04	.05	5.45	94.55	.996
.03	19.85	74.96	.68	4.08	.40	14.29	85.71	.997
.03	19.87	75.04	.69	3.94	.43	14.90	85.10	.997
.03	18.16	68.58	1.77	9.47	1.99	15.75	84.25	.994
.03	17.78	67.14	1.97	10.87	2.21	15.34	84.66	.994

[c] Laboratory analysis, CO.

COMMENT ON ANALYSES OF SAMPLES IN SERIES 1.

The results of analysis of 111 samples of mine air from 29 coal mines are shown in the preceding table. The percentage of black damp in the samples varies from 0.14 to 82.92. The average percentage of carbon dioxide in the black damp is 11.5 per cent, and the average percentage of nitrogen is 89.5 per cent.

The principal factors that probably affect the formation of black damp in coal mines are (1) time of contact between the air and coal; (2) rate of reaction of a particular coal with oxygen, with subsequent formation of some carbon dioxide; (3) temperature of the coal and the air, and (4) presence of moisture. Of these the two first are undoubtedly the most important; hence it is to be expected that different percentages of black damp will be found at different places in the same mine. In a return airway, where the velocity of the air current is high, and the air has been in contact with the coal only a short time, small percentages of black damp are found; however, in the same mine, at a working face, where the air travels slowly, or in an abandoned part of a mine, where the air is stagnant, the percentages of black damp may be high, conditions clearly indicated by many of the results of analyses in the foregoing tables.

If all coals upon reaction with air produced carbon dioxide in the same ratio to the oyxgen consumed, then the percentage composition of black damp should be always the same in all mines. Laboratory experiments show, however, that there is no such constancy, as some coals produce more carbon dioxide in relation to the oxygen absorbed than do others; hence black damp formed by the action of air on different kinds of coal must vary in composition.

A question of interest arises, Should the ratio between the carbon dioxide produced and the oxygen consumed be always the same for each coal? If one takes a sample of fresh coal and treats different portions of it with oxygen under the same conditions, practically identical results will be obtained. If, however, one portion is allowed to weather a long time, or if more moisture is present in one than in another, the results are not so concordant. Probably, also, other factors must be taken into consideration. The analyses given in the preceding table show a fair degree of concordance; that is, samples of black damp from different parts of the same mine do not vary as regards percentage composition of the black damp nearly so much as do samples from different mines, although there is lack of strict concordance which shows that even in the same mine different samples differ in composition.

TEMPERATURE AND HUMIDITY.

Wet and dry bulb temperature readings were taken in 22 of the 29 mines represented in the first series of results. In 6 mines of the 22 the temperature was higher than it should be under the best ventilating conditions. In mine 11 the wet-bulb temperature at one place varied from 74.25° to 78.5° F. However, this place was used only for traveling. The wet-bulb temperature in mine 13, both at the face and in the moving air current, was too high. The proportion of methane was also higher than it should be, ranging from 0.67 per cent in the return 100 feet from the air shaft to 1.94 per cent 25 feet from the seventh south entry. In other words, the introduction of more fresh air into this mine would not only have cooled it, but would have diluted the methane present.

Mine 16 was poorly ventilated. In the return air course where only 4,700 cubic feet of air was passing (samples 5077 and 5078) the carbon dioxide averaged 1.27 per cent and the oxygen 17.74 per cent. More air would certainly have been desirable.

In mine 18 there were high temperatures combined with high carbon dioxide, low oxygen, and high methane content in the air of the manway.

In mine 20, the oxygen content of the air was low, the carbon dioxide and methane contents high, and the temperature high.

RESULTS OF ANALYSES OF SAMPLES IN SERIES 2 TO 6.

In Table 5 following are presented the results of analyses representing mine air collected in different mines in this country. The results have been divided into five series following series 1 in the foregoing table. The samples in series 2 and 3 were collected in mines in West Virginia. The samples in series 4 were collected in an anthracite mine in eastern Pennsylvania, and the samples in series 5 and 6 were collected in two different mines in Indiana. In each mine the sampler started at the intake, and traveled in the direction of the air, collecting samples at certain intervals, so as to show the progressive change in the mine air as it traversed the mine and came in contact with more and more coal.

The table shows the laboratory number of each sample; the place where the sample was collected; the composition of the sample as received; the recalculated analysis showing the atmospheric air, black damp, and methane in the sample; and the composition of the black damp. Certain observations made in connection with the different samples are also given.

TABLE 5.—*Results of analyses of*

SAMPLES IN SERIES 2, FROM

Bottle No.	Sample No.	Distance of point of sampling from intake shaft.	Point of sampling.	Quantity of air per minute.	Temperature at point of sampling.		Relative humidity.
					Wet bulb.	Dry bulb.	
		Feet.		*Cubic feet.*	*° F.*	*° F.*	*Per ct.*
1	6358	2,475	Main air course of west heading	62,040	54	54	100
2	6357	3,000	Air course, off Green heading	16,884	54	54	100
3	6355	3,400	Air course, off Green heading, between rooms 5 and 6	20,216	54	55	94
4	6356	3,800	Air course, off Green heading, between rooms 14 and 15	13,017	53	54	94
5	6354	4,200	Air course, off Green heading, opposite room 24	9,928	53	55	88
6	6361	4,600	Air course, off Green heading, opposite room 33	4,260	54	56	88
7	6353	5,000	Air course, off Green heading, opposite room 42	Air still.	54	56	88
8	6360	5,575	Ritter heading, opposite room 48	5,266	56	57	94
9	6362	6,075	Ritter heading, right side, opposite room 1.	Air still.	55	56	94
10	6352	6,250	Ritter heading, room 55, off left side, at face.	Air still.	56	58	89
11	6359	6,275	Ritter heading, at face of room 2, off right side	Air still.	55	56	94
12	6350	6,575	Ritter heading, 30 feet from upcast air shaft.	5,280	55	55	100

SAMPLES IN SERIES 3, FROM

Bottle No.	Sample No.	Distance of point of sampling from intake shaft.	Point of sampling.	Quantity of air per minute.	Wet bulb.	Dry bulb.	Relative humidity.
1	6372	1,012	12 left air course	Air still.	57	58	94
2	6365	1,512	Face of air course of X entry, off tenth left heading	Air still.	58	59	94
3	6366	1,812	Face of room 3, off tenth right heading	Air still.	58	60	89
4	6369	2,638	Opposite first cross-cut beyond twelfth left heading	Air still.	58	59	94
5	6373	3,438	Between rooms 2 and 3, off twelfth left heading	Air still.	57	58	94
6	6367	3,650	Room 3, off twelfth left heading	Air still.	57	58	94
7	6368	3,738	Room 7, off twelfth left heading	Air still.	58	60	89
8	6374	4,250	Between first and second crosscuts	Air still.	57	58	94
9	6375	5,025	Tenth left entry, opposite fifth crosscut	1,750	57	58	94
10	6370	5,812	Main air course at intersection with ninth right heading	29,000	57	58	94
11	6377	6,612	Main air course, between third and fourth crosscuts, beyond eighth right heading	24,450	56	57	94
12	6378	7,425	Main air course, 40 feet beyond seventh left heading	41,800	57	58	94
13	6376	8,075	Main air course, 60 feet in by fan	61,900	50	54	76

SAMPLES IN SERIES 4, FROM AN ANTHRACITE

Bottle No.	Sample No.	Distance of point of sampling from intake shaft.	Point of sampling.	Quantity of air per minute.	Wet bulb.	Dry bulb.	Relative humidity.
1	6293	200	200 feet from slope	6,400	61	63.5	87
2	6290	470	470 feet from foot of slope	8,800	61	64.5	82
3	6296	682	682 feet from foot of slope, at face	Air still.	61	63.5	87
4	6297	802	802 feet from foot of slope	12,300	61	63.5	87
5	6298	1,527	1,527 feet from foot of slope	10,500	62	64.5	87
6	6301	2,242	2,242 feet from foot of slope	9,700	62	64.5	87
7	6289	3,207	3,207 feet from foot of slope	8,900	64.5	66	87
8	6302	4,320	3,800 feet from foot of slope	6,310	62	64.5	87
9	6292	4,840	4,320 feet from foot of slope	4,360	63	66	85
10	6300	5,110	5,110 feet from foot of slope	Air still.	63	66	85
11	6299	5,915	5,915 feet from foot of slope	7,170	63	66	85
12	6294	6,575	6,575 feet from foot of slope	15,300	63	66	85

mine-air samples, series 2 to 6.

A MINE IN WEST VIRGINIA.

Composition of sample as received.				Recalculated analysis to show air, black damp, and methane.						Composition of black damp.		Specific gravity (air=1).
				Air.			Black damp.		Methane.			
CO_2.	O_2.	CH_4.	N_2.	CO_2.	O_2.	N_2.	CO_2.	N_2.	CH_4.	CO_2.	N_2.	
P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	
0.05	20.83	0.03	79.09	0.03	20.83	78.66	0.02	0.43	0.03	4.4	95.6	1.00
.06	20.80	.03	79.11	.03	20.80	78.54	.03	.57	.03	5.0	95.0	1.00
.06	20.85	.04	79.05	.03	20.85	78.73	.03	.32	.04	8.6	91.4	1.00
.07	20.86	.02	79.05	.03	20.86	78.77	.04	.28	.02	12.5	87.5	1.00
.04	20.90	.02	79.04	.03	20.90	78.92	.01	.12	.02	7.7	92.3	1.00
.10	20.76	.00	79.14	.03	20.76	78.39	.07	.75	.00	8.5	91.5	1.00
.11	20.75	.02	79.12	.03	20.75	78.36	.08	.75	.03	9.6	90.4	1.00
.11	20.71	.03	79.15	.03	20.71	78.20	.08	.95	.03	7.8	92.2	1.00
.09	20.81	.00	79.10	.03	20.81	78.58	.06	.52	.00	10.3	89.7	1.00
.29	20.38	.02	79.31	.03	20.38	76.96	.26	2.35	.02	10.0	90.0	1.00
.10	20.77	.05	79.08	.03	20.77	78.43	.07	.65	.05	9.7	90.3	1.00
.15	20.57	.04	79.24	.03	20.57	77.85	.12	1.56	.04	7.1	92.9	1.00

A MINE IN WEST VIRGINIA.

0.47	19.72	0.00	79.81	0.03	19.72	74.47	.44	5.31	0.03	7.7	92.3	....
.52	19.64	.02	79.82	.03	19.64	74.17	.49	5.65	.02	8.0	92.0	....
.42	19.81	.02	79.75	.03	19.81	74.81	.39	4.94	.02	7.3	92.7	....
.46	19.98	.00	79.56	.03	19.98	75.45	.43	4.11	.00	9.5	90.5	....
.43	19.82	.00	74.85	.03	19.82	74.85	.40	4.89	.03	7.6	92.4	....
.45	19.66	.02	79.87	.03	19.66	74.02	.42	5.85	.02	6.7	93.3	....
.67	19.54	.01	79.78	.03	19.54	73.79	.64	5.99	.01	9.7	90.3	....
.46	19.63	.08	79.83	.03	19.63	74.13	.43	5.70	.08	7.0	93.0	....
.51	19.76	.01	79.72	.03	19.76	74.62	.48	5.10	.01	8.6	91.4	....
.35	20.14	.00	79.51	.03	20.14	76.05	.32	3.45	.01	8.5	91.5	....
.35	20.24	.02	79.39	.03	20.24	76.43	.32	2.96	.02	9.8	90.2	....
.40	20.13	.00	79.47	.03	20.13	76.01	.37	3.46	.00	9.7	90.3	....
.20	20.43	.03	79.34	.03	20.43	77.15	.17	2.19	.03	7.2	92.8	....

MINE IN EASTERN PENNSYLVANIA.

0.09	20.80	0.05	79.06	0.03	20.80	78.55	0.06	0.51	0.05	10.5	89.5	....
.11	20.74	.18	78.97	.03	20.74	78.32	.08	.65	.18	11.0	89.0	....
.15	20.62	.36	78.87	.03	20.62	77.86	.12	1.01	.36	10.6	89.4	....
.12	20.68	.19	79.01	.03	20.68	78.09	.09	.92	.19	8.9	91.1	....
.13	20.69	.24	78.94	.03	20.69	78.13	.10	.81	.24	11.0	89.0	....
.13	20.65	.34	78.88	.03	20.65	77.98	.10	.90	.34	10.0	90.0	....
.16	20.48	.65	78.71	.03	20.48	77.34	.13	.65	.65	8.7	91.3	....
.09	20.52	.80	78.59	.03	20.52	77.49	.06	.80	.80	5.0	95.0	....
.16	20.49	.94	78.41	.03	20.49	77.37	.13	1.04	.94	11.0	89.0	....
.19	20.37	1.04	78.40	.03	20.37	76.92	.16	1.48	1.04	9.8	90.2	....
.20	20.29	1.17	78.34	.03	20.29	76.62	.17	1.72	.24	9.0	91.0	....
.22	20.39	1.01	78.38	.03	20.39	77.00	.19	1.38	1.01	12.3	87.7	....

TABLE 5.—*Results of analyses of*

SAMPLES IN SERIES 5,

Bottle No.	Sample No.	Distance of point of sampling from intake shaft.	Point of sampling.	Quantity of air per minute.	Temperature at point of sampling.		Relative humidity.
					Wet bulb.	Dry bulb.	
		Feet.		*Cubic feet.*	°*F.*	°*F.*	*Per ct.*
1	6328	50	Main east entry at air course	10,100	66	67	95
2	6322	562	Main east entry	15,000	66	67	95
3	6321	1,300	.....do	13,680	66	67	95
4	6331	2,060	.....do	7,980	66	67	95
5	6329	2,600	.....do	7,790	65	66	95
6	6330	3,560	No. 1 room, off second west entry	Air still.	66.5	67	97
7	6327	4,025	Room 2, off second west entry, off main east entry	Air still.	65	66	95
8	6326	4,175	Room 7, second west entry, off main east entry	Air still.	66	67	95
9	6323	4,400	Room 9, second west entry, off main east entry, at face	Air still.	67	68	98
10	6324	5,100	Second west air course at overcast on first east entry	1,470	66	67	95
11	6325	6,500	Return at junction of main east entry and main north entry	16,000	67	68	95

SAMPLES IN SERIES 6,

Bottle No.	Sample No.	Distance of point of sampling from intake shaft.	Point of sampling.	Quantity of air per minute.	Wet bulb.	Dry bulb.	Relative humidity.
1	6303	(*a*)	Foot of air shaft, intake air	35,700	65	66	95
2	6305	2,000	Fourth west air course	9,150	60	61	94
3	6306	3,000	.....do	13,500	61	62	94
4	6307	4,000	.....do	11,425	65	66	95
5	6308	5,300	Face of room in eighth north entry, off fourth west air course	Air still.	63	63	100
6	6309	6,300	Face of eighth north entry, off fourth west air course	7,200	64	65	95
7	6310	6,900	Room 9, first south entry, off third west air course	Air still.	66	67	95
8	6311	7,000	Room 1, at face, off first south entry, off third west air course	Air still.	65	66	95
9	6312	8,100	Room 2, near face at breakthrough, off eighth north entry, off fourth west air course	8,710	65	66	95
10	6313	9,800	Fourth west air course, return side	8,710	65	66	95
11	6314	10,700	.....do	13,000	66	67	95
12	6315	11,600	.....do	15,570	65	66	95
13	6316	13,000	.....do	16,575	65	66	95

a Sample taken at foot of shaft.

mine-air samples, series 2 to 6—Continued.

FROM A MINE IN INDIANA.

Composition of sample as received.				Recalculated analysis to show air, black damp, and methane.						Composition of black damp.		Specific gravity (air=1).
				Air.			Black damp.		Methane.			
CO_2.	O_2.	CH_4.	N_2.	CO_2.	O_2.	N_2.	CO_2.	N_2	CH_4.	CO_2.	N_2.	
P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	
0.05	20.87	0.00	79.08	0.03	20.87	78.81	0.02	0.27	0.00	6.9	93.1	....
.08	20.81	.00	79.11	.03	20.81	78.59	.05	.52	.00	8.8	91.2	....
.06	20.82	.00	79.12	.03	20.82	78.62	.03	.50	.00	5.7	94.3	....
.09	20.80	.01	79.10	.03	20.80	78.54	.06	.56	.01	9.7	90.3	....
.19	20.55	.00	79.26	.03	20.55	77.60	.16	1.66	.00	8.8	91.2	....
.56	19.55	.01	79.88	.03	19.55	73.82	.53	6.06	.00	8.0	92.0	....
.76	19.04	.07	80.13	.03	19.04	71.90	.73	8.23	.07	8.2	91.8	....
.74	19.00	.07	80.19	.03	19.00	71.74	.71	8.45	.07	7.8	92.2	....
.85	18.67	.13	80.35	.03	18.67	70.50	.82	9.85	.13	7.7	92.3	....
.54	19.53	.04	79.89	.03	19.53	73.75	.51	6.14	.04	7.7	92.3	....
.55	19.59	.02	79.84	.03	19.59	73.97	.52	5.87	.02	8.1	91.2	....

FROM A MINE IN INDIANA.

0.04	20.90	0.00	79.06	0.04	20.90	79.06	0.00	0.00	0.00	0.0	0.0	....
07	20.78	.10	79.05	.03	20.78	78.47	.04	.58	.10	6.5	93.5	....
.11	20.70	.10	79.09	.03	20.70	78.17	.08	.92	.10	8.0	92.0	....
.14	20.67	.13	79.06	.03	20.67	78.05	.11	1.01	.13	9.8	90.2	....
.25	20.43	.41	78.91	.03	20.43	77.15	.22	1.76	.41	11.1	88.9	....
.21	20.43	.22	79.14	.03	20.43	77.15	.18	1.99	.22	8.3	91.7	....
.25	20.31	.26	79.18	.03	20.31	76.69	.22	2.49	.26	8.1	91.9	....
.49	19.89	.52	79.10	.03	19.89	75.11	.46	3.99	.52	13.9	86.1	....
.24	20.57	.14	79.05	.03	20.57	77.68	.21	1.37	.14	13.3	86.7	....
.37	20.36	.29	78.98	.03	20.36	76.88	.34	2.10	.29	13.9	86.1	....
.76	19.58	.18	79.48	.03	19.58	73.94	.73	5.54	.18	11.6	88.4	....
.55	19.67	.16	79.62	.03	19.67	74.28	.52	5.34	.16	8.9	91.1	....
1.27	18.08	.12	80.53	.03	18.08	68.27	1.24	12.26	.12	9.2	90.8	....

COMMENT ON RESULTS OF SAMPLING AND ANALYSIS.

SAMPLES IN SERIES 2.

It will be noted that the first sample of series 2 was collected 2,475 feet from the intake, and the succeeding samples at greater distances, until the last one was taken 6,575 feet from the intake. In general, the first samples were lower in carbon dioxide content and higher in oxygen content, and consequently contained less black damp, but the change was not so marked as in the samples of other series. The composition of the black damp was fairly constant, ranging between 4.4 per cent and 12.5 per cent carbon dioxide and between 87.5 and 95.6 per cent nitrogen. The average composition of the black damp was carbon dioxide, 8.4 per cent; nitrogen, 91.6 per cent.

SAMPLES IN SERIES 3.

The first eight of the samples in series 3 were collected in still air at working faces. The proportion of carbon dioxide ranged from 0.20 to 0.67 per cent, the oxygen content ranged from 19.54 to 20.43 per cent, and the percentage of black damp ranged from 5.75 to 6.13 per cent, a small but still noticeable increase. The last five samples were collected in the air current and the greater purity of the air is noticeable. The composition of the black damp was remarkably constant, ranging from 6.7 to 9.8 per cent carbon dioxide and from 90.2 to 93 per cent nitrogen. The average composition of the black damp was carbon dioxide, 8.4 per cent; nitrogen, 91.6 per cent.

SAMPLES IN SERIES 4.

The change in the composition of the air as it traversed the mine is much better indicated by the data regarding the samples in series 4 than by those for the samples in the two preceding series, because the volume of air traversing the place where each sample was collected did not differ enough to influence markedly the percentage change in the carbon dioxide and oxygen contents. Some irregularities due to this cause were, however, noticeable. At the place where sample 6294 was collected, 15,300 cubic feet of air was passing, whereas at the place where sample 6299 was collected, 7,170 cubic feet of air was passing; this difference in the quantity of air passing made the percentage of black damp in sample 6294 (1.57) appear less, whereas in reality the cubic feet of black damp was greater, being 240 cubic feet (15,300 by 1.57) as against 136 cubic feet (7,170 by 1.89) for sample 6299.

SAMPLES IN SERIES 5.

A noticeable increase in the percentage of black damp is seen in the samples in series 5. Samples 6330, 6327, 6326, and 6323 were collected at working faces in still air, and consequently were much higher in black damp than the other samples. These samples also showed a progressive increase in black damp content as the distance from the intake was increased. The greatest vitiation in the moving air was noticeable in samples 6324 and 6325.

The composition of the black damp was nearly constant. The average proportion of carbon dioxide was 9.8 per cent, and of nitrogen 90.2 per cent.

SAMPLES IN SERIES 6.

Progressive vitiation of the air is also noticeable in the samples of series 6. A noticeable feature is the large increase of black damp in sample 6316, as compared with the proportion in sample 6315. The average percentage of carbon dioxide in the black damp is 10.2 per cent and of nitrogen 89.8 per cent.

EFFECTS OF TEMPERATURE AND HUMIDITY AND OTHER FACTORS.

The temperatures in the mine where the samples of series 2 were collected were all moderate, in fact, highly desirable working temperatures. The carbon dioxide content was not high, but the oxygen content was satisfactory and practically no methane was present. No fault could be found with the condition of the air in this mine.

In the mine where the samples of series 3 were collected the carbon dioxide content was higher than in the foregoing mine, the oxygen content lower, and the temperatures a little higher. However, according to modern ideas of the purity of air and the effects of mine air on individuals, one would say the conditions of the air in this mine were all right.

The same is true of the mine where the samples of series 4 were collected, except that the ventilation needed closer watching because of the presence of methane in the air current. A proportion of 1.01 per cent of methane in an airway (sample 6294, where 15,300 cubic feet of air was passing) is rather high. However, the sample represented an anthracite mine in which dust does not constitute the menace that it does in bituminous mines. Many of these mines are extremely gaseous; consequently more difficulty is experienced in keeping the methane down to small percentages than in most bituminous mines.

In the mine where the samples of series 5 were collected conditions were fairly good. At one working face (sample 6323) the oxygen content was 18.67 per cent and the carbon dioxide content 0.85 per cent. The mine was not gaseous. The temperatures were satisfactory.

In the mine where the samples in series 6 were collected, one sample (No. 6316) was high in carbon dioxide (1.27 per cent) and low in oxygen (18.08 per cent). This sample was collected in the return air where 16,575 cubic feet of air was passing. The temperatures were satisfactory.

EFFECTS OF LEAKAGE OF AIR THROUGH DOORS, BRATTICES, ETC.

Necessarily the composition of the air in an entry is influenced greatly by the leakage of air through stoppings, doors, brattices, and overcasts. For instance, the air may be practically normal at a particular place in an entry, not having traveled very far in the mine, and hence not having reacted with much coal. A short distance farther, however, a decided change in its carbon dioxide and oxygen content might be caused by badly vitiated air leaking through a door. That mine will have the tightest doors, overcasts, etc., in which the air shows a gradual and uniform change in composition as it travels through the mine.

INFLAMMABLE GAS IN MINES.

Although this report deals primarily with the vitiation of coal-mine air by changes in the content of carbon dioxide and of oxygen, some reference to the presence of inflammable gas (methane) is required, because coal-mine ventilation is largely governed by the quantity of inflammable gas entering the workings.

For instance, the bituminous-mine law of Pennsylvania states that in a nongaseous mine the minimum quantity of air shall be not less than 150 cubic feet per minute for each person employed, and in a mine wherein explosive gas is being generated in such quantities that it can be detected by an approved safety lamp, the minimum quantity of air shall be not less than 200 cubic feet per minute for each person employed therein, and as much more in either case as one or more of the inspectors may deem requisite. Further, under the law mentioned, the use of open lights is prohibited in any entry, airway, traveling way, room, or any other working place where explosive gas is likely to be encountered, and in all such places locked safety lamps must be used exclusively.

In other words, the fact that coal mines generate inflammable gas in greater or less quantities has necessitated the introduction of fresh air to dilute the gas, and this natural gaseous condition of many coal mines has had a great deal to do with keeping the air of coal mines in good condition. The presence of inflammable gas introduces the danger of disastrous explosions, especially in mines where the air is not controlled properly, but this danger, by leading to the continuous introduction of immense volumes of fresh air, year after year, has undoubtedly been the chief element in assuring good ventilation.

In general the air in mines that are termed "gaseous," and consequently are required to have large volumes of air coursing through them and must be inspected more thoroughly to keep all parts of the workings free of inflammable gas, is higher in oxygen, lower in carbon dioxide, lower in temperature, and moves faster, and in all ways has a higher standard of purity than the air in those mines that are termed nongaseous and hence are not required by law to have as much fresh air passing through them, and, in which, because they are not menaced by inflammable gas, the ventilation is not regulated as carefully.

OCCURRENCE AND COMPOSITION OF GAS IN ROCK STRATA OF THE CRIPPLE CREEK GOLD-MINING DISTRICT, COLORADO.

The senior authors of this paper, while in Colorado on other official business, made a trip to the Cripple Creek gold-mining district to get more data than is at present available regarding the composition of the gas that issues from the rock strata into the gold mines of the district. This gas was said to cause suffocation, and hence to be a menace to life. The data presented herein relate principally to the composition of this gas and its effects on men and on lights.

It is estimated that 25 to 100 miners have been killed by the rock gas in the 25 years that mining has been vigorously carried on at Cripple Creek. Many men have had narrow escapes from death, some of them having been incapacitated for days. In addition, on certain days men can not enter some of the workings. At a few mines fans are used to force outside air into the mines, thus improving conditions in large measure, but even this plan, as used at Cripple Creek, is not entirely adequate at all times.

ORIGIN OF THE STRATA GAS.

Lingren and Ransome[a] believed that the gas found in the rocks of the Cripple Creek mining district represents the last exhalations of the extinct Cripple Creek volcano. In support of this they stated that little timbering is used in the mines, hence one can not account for the decrease of oxygen or increase of carbon dioxide by oxidation of timber. Further, there is only a small proportion of pyrite and carbonates present in the rocks and ores as compared to that in many other mines entirely free from gas. Moreover, no gas occurs in the oxidized zone, showing that oxidation can not have anything to do with it, and as the gas increases with depth it must be mainly accumulated in strata at depths below those penetrated by the deepest mines of this district.

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[a] Lingren, W., and Ransome, F. L., Geology and gold deposits of the Cripple Creek mining district: U. S. Geol. Survey, Prof. Paper 54, 1906, p. 257.

EFFECTS OF BAROMETRIC PRESSURE ON OUTFLOW OF STRATA GAS.

The gas is confined in the rock under such low pressure that variations in the outside atmospheric pressure may materially affect the outflow of gas into the mines. Also, at these mines where fans force air in, thereby putting the workings under about 6 or 7 inches of water pressure (about 0.5 inch of mercury), the workings are more or less free from the rock gas which is held back in the pores and crevices of the rocks. The variation in outside atmospheric pressure is easily more than 0.5 inch of mercury, and the effect of the barometric pressure on the outflow of gas is appreciated by mining men.

COLLECTION OF SAMPLES OF GAS IN FOUR METAL MINES.

One of the authors collected samples of gas in the Mary McKinney, Anaconda, Midget, and Cresson mines. Data regarding the samples are contained in Table 8. General remarks on some of the mines represented in the table are presented as bearing on the data given in the table.

OBSERVATIONS ON GAS IN MIDGET MINE.

The Midget mine is situated on the west slope of Gold Hill. The workings are partly in breccia and partly in the fine-grained gray gneiss common to the district. The mine has 10 levels. From the shaft to the tenth level is about 900 feet. About 20 men work underground on a leasing system. As regards the men in the levels where samples of gas were collected, four men were in the seventh level, four men on the eighth, and nobody, on account of bad gas conditions, on the ninth or tenth. In the afternoon of the day of sampling the men had to leave the eighth level on account of the gas. Gas conditions were said to be worse than usual at the mine on that day.

The Midget mine uses a pressure system of ventilation. On the surface is a 5-foot Sturtevant fan driven by a 20-horsepower motor which forces air through an air compartment in the shaft to a point below the second level, whence the air spreads into the various levels. In the drifts at various distances from the shaft are air doors, built of 1-inch boards and tightened with canvas. Thus, a small pressure, 3 or 4 inches water gage, is placed on the mine workings, sufficient to check in part the outflow of gas from the rocks and enable the men to do more work than they could without the fan. But when the outflow of gas is stronger than usual, workmen are sometimes driven from the lower levels, and occasionally can not reenter for days.

The Conundrum mine was the first in the Cripple Creek district to install this system of ventilation. This mine adjoins the Midget.

Of the series of samples collected at the Midget mine, only one, No. 664, was collected outside the pressure area or zone and beyond the door. Candles burned freely inside the door, but 20 feet beyond they went out, indicating at this point less than 17 per cent of oxygen. When the door was opened the air rushed through with sufficient strength to blow out the lights.

GENERAL OBSERVATIONS REGARDING GASEOUS CONDITIONS IN ANACONDA MINE.

The workings of the Anaconda mine in the town of Anaconda extend through Gold Hill. The mine is worked through an adit having a portal at Anaconda. The prevailing country rock is breccia, with some irregular bodies of latite-phonolite and a few dikes of phonolite and basalt.

The Anaconda shaft is reached by means of an adit 1,135 feet long. The fourth and fifth and lower levels are at times much troubled by rock gas. The progressive vitiation of the air in the fourth drift of the fourth level is shown by the data presented in Table 6 regarding the first six samples from the Anaconda mine. In taking sample 691, 300 feet north of the shaft, which contained 9.02 per cent of oxygen and 5.51 per cent of carbon dioxide, the sampler advanced with an acetylene lamp held near his mouth, until the lamp went out (about 12 or 13 per cent oxygen), then reached down and collected the sample near the floor. The dangerous stratification of the gas is well shown by these analyses. At the height of a man's mouth the air was breathable, but at the floor a man would collapse quickly because of the small amount of oxygen (5.51 per cent) there. Similar stratification is shown by samples taken at other points.

It was noticed on another occasion that a lighted candle would burn fairly well at one point in a drift, but become extinguished further along, although great care was taken that it should not be extinguished by a sudden movement or jerk. At a point still further in the drift it would stay lighted. Usually, though, the nearer one approached the breast of a drift containing much rock gas the worse the air became.

OBSERVATIONS ON GAS IN CRESSON MINE.

The Cresson mine is on Raven Hill about two and one-half miles from the Midget mine and two miles from the Anaconda mine. It has 13 levels. The prevailing country rock is andesite breccia.

A wooden door made as tight as possible is placed in each drift beyond the workings and a compressed-air pipe is run through a hole in the door and is sealed around as tightly as possible. A valve placed inside the door provides for turning on the compressed air. When the air is turned on the rock gas is kept back. The effectiveness of this plan is shown by the analyses of samples collected inside and beyond one of these doors.

In collecting sample 760 the collector advanced 10 feet beyond where the air was comparatively good, holding his breath, then quickly snapped the sealed and evacuated glass sample bottle, whereupon the mine gas immediately filled the bottle, after which he quickly came out. Even so he had a narrow escape, for his knees became weak and his mind slightly hazy, owing no doubt to inadvertently breathing a little of the atmosphere. As soon as he came to better air 10 feet away he felt all right.

Sample 760 showed the effect of the compressed air in holding back the rock gas. At the height of a man's head just at the door the oxygen content of the atmosphere was 16.23 per cent, whereas 10 feet beyond the door the oxygen content was only 2.69 per cent. This sample more closely approximated the pure rock gas than any other collected.

So-called blowers of gas are difficult to find in the Cripple Creek mines. The escape of gas from the rocks usually is uniform from thousands of small pores rather than from large outbursts at one particular place. If one calculates the air-free composition of this sample (No. 760), by eliminating the nitrogen and oxygen according to the proportions found in atmospheric air, the composition becomes 12.69 per cent carbon dioxide and 87.31 per cent nitrogen. These figures show the composition of the pure rock gas, if one assumes that the air in the sample as collected was due to dilution of the rock gas by the mine air.

Apropos of the occasional small outbursts of gas from the rocks, it is interesting to mention at this point an incident related by the superintendent of the Midget mine. In the course of his duties in the mine he was leaning against the wall of a drift with his face close to the rock, talking to another man. Suddenly he felt dizzy and breathless and his knees became weak. Although not knowing the cause of his distress he changed his position and soon felt better. Then it occurred to him that possibly a small feeder of gas was finding its exit close to where he had been standing; so he put his carbide lamp up against the rock at that place. It was immediately extinguished, showing that his assumption had been correct.

TABULATED DATA.

Table 6, presenting detailed data regarding the samples taken in the four mines under consideration, follows.

TABLE 6.—*Data on gas samples collected in four mines in the Cripple Creek district.*

MIDGET MINE.

Sample No.	Place of taking sample.	Bed.	Temperature.		Relative humidity.	Barometer.	Candle burned.	Acetylene lamp burned.	CO_2.	O_2.	Combustible gas.	N_2.	Total.	Remarks.
			Wet bulb.	Dry bulb.										
			°*F.*	°*F.*	*P. ct.*	*Inches.*			*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	
781	Eighth level, north drift	Midget Murray vein.	73	76	88	21.6	No	Yes	3.66	16.57	0.00	79.77	100	No men were present at working place.
776	Eighth level, in Olson-Hollengrain stope.						Yes	Yes	1.00	18.92	.00	80.08	100	End of air line was 50 feet from stope; top of stope lay at angle of 45° from end of air line.
663	Eighth level, at breast	Midget Murray vein.	60	65	75		Yes	Yes	.93	20.03	.00	79.04	100	Two men working at breast when sample was taken; compressed air had been turned on this breast for two hours prior to taking sample; breast was 75 feet from end of air line.
770	Raise, 40 feet from breast	Intermediate vein.	63.5	69	76		No	No [a]	8.84	10.06	Trace.[b]	80.30	100	No compressed air; nobody working in this place.
296	Ninth level, north drift, 250 feet from shaft.	Conundrum vein	63	69	76	21.66	Yes [c]		2.08	18.53	.00	79.39	100	No men working on ninth level.
769	In shaft at ninth level, 830 feet from surface.		61	66	74				.11	20.79	.00	79.10	100	Air in shaft would not move vanes of anemometer.
400	Seventh level, 375 feet northwest of shaft.	Intermediate vein.	63.5	74	59			No [d]	8.68	10.86	.00	80.46	100	No men working here.
794	Seventh level, 250 feet north of shaft, 75 feet from breast.	Midget Murray vein.						No	7.35	11.63	.00	81.02	100	Do.
664	Sixth level, outside of pressure zone, about 200 feet beyond air line.		50.5	54	81				5.09	15.06	.00	79.85	100	

[a] Would burn 1 foot above where sample was collected.
[b] Less than 0.02 per cent.
[c] Feebly.
[d] Burned 2 feet above where sample was taken.

TABLE 6.—*Data on gas samples collected in four mines in the Cripple Creek district*—Continued.

ANACONDA MINE.

Sample No.	Place of taking sample.	Bed.	Temperature.		Relative humidity.	Barometer.	Candle burned.	Acetylene lamp burned.	CO_2.	O_2.	Combustible gas.	N_2.	Total.	Remarks.
			Wet bulb.	Dry bulb.										
			°*F.*	°*F.*	*P. ct.*	*Inches.*			*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	
691	Fourth level, fourth drift, 300 feet north of shaft.		56	59	85			(*a*)	9.02	5.51	Trace.[b]	85.47	100	
966	Fourth level, fourth drift, 275 feet from shaft.		56	59	85	21.6			7.96	7.50	.02	84.52	100	Nobody working on this level; influx of gas in the afternoons and about one-third of the time in the morning; generally prevents work in this level.
937	Fourth level, fourth drift, 250 feet from shaft.							No[c]	5.43	11.78	.00	92.79	100	
750	Fourth level, fourth drift, 150 feet from shaft, near floor.							No	8.09	7.19	Trace.[b]	84.72	100	
694	Fourth level, fourth drift, at roof, 7 feet from floor.								1.64	18.30	.00	80.06	100	
948	Fourth level, fourth drift, 5½ feet from floor.						Yes[d]		1.51	18.44	.00	80.05	100	
690	Fifth level, at breast of north drift, 200 feet below fourth level.		64	68	82		No	Yes	1.69	17.70	.00	80.61	100	Two men were working here; compressed air had been turned on this breast up to three minutes before sample was taken.
747	Fifth level, at foot of shaft		57.5	60.5	85		Yes		.32	20.46	.00	79.22	100	Air was being forced into this level from a fan on fourth level.

MARY McKINNEY MINE.

Sample No.	Place of taking sample.	Bed.	Wet bulb.	Dry bulb.	Relative humidity.	Barometer.	Candle burned.	Acetylene lamp burned.	CO_2.	O_2.	Combustible gas.	N_2.	Total.	Remarks.
761	Eighth level, about 800 feet from surface, No. 15 raise, up about 15 feet from level of drift and about 1,400 feet from shaft.	No. 2 vein	56	60	80	21.87			1.82	10.70	.00	87.48	100	Nobody was working in this raise.
762	Eighth level, 180 feet north of Black vein, No. 12 north drift, 1,500 feet from shaft.		58.5	61	88			No[e]	7.54	8.01	.00	84.45	100	Nobody was working at this place; the gas sometimes fills entire drift; conditions were worse than usual at time of sampling.

780	Eighth level, at roof, No. 12 north drift, at junction of Black vein drift.	....	....	....	....	....	....	....	Yes...	4.17	13.87	Trace.[b]	81.96	100	
908	Junction of No. 2 vein and main crosscut from shaft, 1,250 feet from shaft.[f]	No vein.	....	54.5	58	82	....	....	....	.25	20.50	.02	79.23	.100	
	CRESSON MINE.														
797	Eleventh level, at pressure door, 500 feet from shaft, at floor.	....	....	....	69	....	....	....	No....	8.90	7.03	.00	84.07	100	Door was open slightly when sample was collected.
795	Eleventh level, at pressure door, 5½ feet above floor.	....	....	....	....	....	....	....	Yes...	2.85	16.23	.00	80.92	100	
760	Beyond air door, about 10 feet beyond samples 797 and 795.	....	....	....	....	....	....	....	....	11.08	2.69	.03	86.20	100	See pp. 60, 62 for extended comments.
759	Eleventh level, under 1103 stope, 400 feet from shaft.	....	....	60	64	....	....	Yes...	....	2.35	17.19	.00	80.46	100	Sample collected 100 feet inside door where samples 797, 795, and 760 were collected.
771	Eleventh level, at the shaft.......	....	....	64.5	65.3	81	....	....	....	.29	20.56	.00	79.15	100	
754	Seventh level, 700 feet from shaft, near bottom of drift.	....	....	61	64	86	....	No....	Yes...	1.01	14.05	Trace.[b]	84.94	100	
753	Seventh level, 700 feet from shaft, at top of drift.	....	....	61	64	86	....	No....	Yes...	.60	16.74	.00	82.66	100	
772	Seventh level, 700 feet from shaft, at center of drift.	....	....	61	64	86	....	No....	Yes...	.62	16.65	.00	82.73	100	
943	Seventh level, 600 feet from shaft..	....	....	....	....	....	....	....	....	.39	20.03	.00	79.58	100	
944	Seventh level, 650 feet from shaft..	....	....	....	....	....	....	....	....	.51	17.78	.00	81.71	100	

[a] Carbide lamp went out at roof and floor but burned about 5½ feet above floor.
[b] Result corresponds with author's laboratory experiments, which showed that acetylene lamp is extinguished when oxygen content of atmosphere drops to about 12 or 13 per cent
[c] Less than 0.02 per cent.
[d] Faulty.
[e] Would burn at roof.
[f] Shaft was acting as a downcast, and sample was collected 250 feet from upcast; air seemed good.

SPECIAL AIR SAMPLES FROM MARY M'KINNEY MINE.

The Mary McKinney mine is situated on the south side of Squaw Gulch, opposite the town of Anaconda. The first ore was shipped in 1893. The workings are mainly in breccia and phonolite. Data on the air samples collected in this mine by one of the authors is shown in Table 8.

At the instance of the authors mine-air samples were collected by A. G. Suydam, a mining engineer of Cripple Creek, for 22 days, almost daily, in the Mary McKinney mine, in the No. 12 north drift, on the 800-foot level, about 1,800 feet from the shaft. The point of sampling was close to a fissure in the rock from which a "feeder" of rock gas intermittently issued.

Table 7 following shows the number of samples collected at this point by Mr. Suydam, date of sampling, results of analyses, and the direction of the wind and the barometric pressure on the date the samples were collected:

TABLE 7.—*Data regarding gas samples collected near feeder in Mary McKinney mine.*

Sample No.	Date of collection of sample.	Analysis.			Direction of wind.	Barometric pressure.	Condition of weather.	Strength of wind.
		CO_2	O_2	N_2				
	1915.					*In. Hg.*		
6987	Nov. 1	0.24	20.58	79.18	N. to NW	22.25	Clear	Mild.
6984	Nov. 3	12.06	2.97	84.97	SW	22.26	do	Do.
6986	Nov. 5	13.27	.94	85.79	S. to SW	22.16	Partly cloudy	Do.
6981	Nov. 9	8.84	7.83	83.33	S. to SW	22.06	do	Do.
6983	Nov. 11	.17	20.75	79.08	NW. to N	21.96	Clear and cold	Strong.
6980	Nov. 13	11.05	3.39	85.56	S. to SW	21.93	Partly cloudy	Mild.
6988	Nov. 15	7.86	8.89	83.25	N. to NW	22.00	Clear and cold	Brisk.
6989	Nov. 22	.41	20.64	78.95	N. to NW	22.16	Clear	Mild.

In addition to the results given above some interesting observations were made by Mr. Suydam as to the effect of different wind and barometer conditions on the air in the drift of the Mary McKinney mine as indicated by candles and acetylene lights. These data are shown in Table 8, following.

TABLE 8.—*Data regarding effect of wind and barometer conditions on air in drift of Mary McKinney mine.*

Date.	Barometer.	Wind.		Sky.	Remarks.
		Direction.	Strength.		
1915. Oct. 11	21.875	S. to S. W.	Mild	Cloudy	Mine closed because of strata gas.
12	21.955	N. to N. E.	Calm	Clear	Air good in drift.
14	21.985	N. E. to N	do	Cloudy	Some strata gas in drift.
15	22.030	N. E. to N	Strong	do	Air good.
16	22.130	S. W. to S	Calm	do	Do.
17	22.185	N. to N. W	Mild	Clear	Do.
19	22.175	do	do	do	Do.
21	22.240	S. to S. E	do	do	Do.
22	22.350	do	Calm	do	Some strata gas in drift.
23	22.295	do	do	do	Do.
25	22.200	N. to N. W	do	do	Air good.
26	22.290	N. to N. E	Light	do	Do.
27	22.380	N. to N. W	Calm	do	Do.
28	22.385	do	do	do	Do.
30	22.235	S. W. to S. to W	Brisk	Partly cloudy.	Strata gas in drift.
Nov. 2	22.260	W. to S. W. to N. W.	Mild	do	Air good.
10	21.750	S. to S. W	do	Fog	Do.
16	21.800	N. to N. W	do	Clear (cold)	Strata gas in drift.
18	....	do	do	do	No gas; air good.
19	22.185	N. W. to N	do	Clear	Air good.

Regarding those samples that were collected and analyzed, the total number of samples collected was too small to permit the drawing of rigid conclusions. With one exception (sample No. 6988) the largest amounts of carbon dioxide and the smallest amounts of oxygen were found in samples collected when the wind was from the south or southwest. This relation agrees with statements of some mining men that when the wind came from the south or southwest the most rock gas entered the mines.

Table 7 shows that rock gas was present in the north drift of the Mary McKinney mine when the wind was south or southwest in 4 cases and when it was north in 2 cases. Also in 10 cases the air was good in the drift when the wind was from the north, and in 3 cases when it was from the south or southwest. Also a consistent relation could not be traced between the barometric pressure and the presence of rock gas.

Some of the mining men of the Cripple Creek district have a theory that when the wind comes from the south or southwest it sweeps up canyons where the rock outcrops. These, being somewhat porous, permit the entrance of atmospheric air, which forces the rock gas into the mine workings.

COMPOSITION OF STRATA GAS SAMPLES CALCULATED ON AIR-FREE BASIS.

It was impossible to procure samples of pure strata gas as it issued from the rocks in the Cripple Creek mines during the visit of one of the authors. Entrance was made as far as it was possible to penetrate into some of the drifts that were most affected. A sample (No. 760) containing 2.69 per cent oxygen was obtained from the Cresson mine and was the sample containing the largest percentage of strata gas. Undoubtedly if one had been able to penetrate 15 or 20 feet farther into the drift a sample practically devoid of oxygen could have been procured. One can determine rather closely the composition of the strata gas, however, by selecting those samples that contained the smallest percentages of oxygen and calculating them air-free, as has been done in the following table:

Air-free composition of samples containing small percentages of oxygen.

MIDGET MINE.

Sample No.	CO_2.	O_2.	Combustible gas.	N_2.	Total.	Calculated air-free.	
						CO_2.	N_2.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
770	8.84	10.86	0.00	80.30	100.00	18.37	81.63
400	8.68	10.86	.00	80.46	100.00	18.03	81.97
794	7.35	11.63	.00	81.02	100.00	16.53	83.47
ANACONDA MINE.							
966	7.96	7.50	0.00	84.54	100.00	12.40	87.60
937	5.43	11.78	.00	82.79	100.00	12.41	87.59
691	9.02	5.51	.00	85.47	100.00	12.23	87.77
750	8.09	7.19	.00	84.72	100.00	12.32	87.68
MARY McKINNEY MINE.							
762	7.54	8.01	0.00	84.45	100.00	12.20	87.8
976	5.88	10.71	.00	83.41	100.00	12.03	87.97
CRESSON MINE.							
797	8.90	7.03	0.00	84.07	100.00	13.4	86.6
760	11.08	2.69	.00	86.23	100.00	12.71	87.29

These calculations show that the composition of the strata gas varied between 12.03 and 18.37 per cent of carbon dioxide and 81.63 and 87.97 per cent of nitrogen. The average of all of the results is 13.87 per cent of carbon dioxide and 86.13 per cent of nitrogen. Thus, the rock gas is a mixture of carbon dioxide and nitrogen. In making the calculations it was assumed that no oxygen is present in the gas as it issues from the rock, and that any air in the samples was due to dilution of the rock-strata gas by the air of the mine. This assumption appears to be justified because in a drift more or less filled with rock-strata gas the gas becomes less and less diluted with oxygen as one travels from the good air of the mine farther and farther into the bad air of the drift.

A tendency was noticed among the mining men of Cripple Creek to speak of the strata gas as carbon dioxide or at least as if carbon dioxide was the predominating constituent. This is not the case. Nitrogen is much in excess. The bad effects produced are principally due to the fact that the rock gas so dilutes the air of the mines that the oxygen falls to a point where lights will not burn or so low that life is endangered.

In the authors' opinion the acetylene light should not be used as the sole warning against the presence of gas in these mines. It is true that where the acetylene lamp burns there is enough oxygen (12 to 13 per cent) in the air to support life, but under such conditions the air only a short distance beyond in a drift or at the floor may be fatal to life. The warning of a candle flame affords a much wider margin of safety. At some mines the operators allow no work to be performed where a candle will not burn.

EFFECT ON MEN OF PARTIAL PRESSURES OF OXYGEN.

The effects of carbon dioxide and oxygen on men and lights have been discussed in a previous part of this report. A point that can be profitably emphasized here is the effect of the partial pressure of the oxygen on men.

The effects of working in bad air of the Cripple Creek mines are typical of the effects produced by any low oxygen and high carbon dioxide atmospheres. After a day's work the men suffer a feeling of oppression, heaviness, and lassitude, or sleepiness, and a loss of appetite, the degree of distress depending, of course, upon the extent of vitiation of the air. When the air gets very bad, say when a candle will not burn, slight exertion causes breathlessness. Much exposure in bad air brings on headaches and nausea and complete exhaustion. That more fatalities do not occur is due to the fact that the men fairly well appreciate the warning of their lamps and are careful about venturing where acetylene lamps will not burn. Collapse may be very sudden in atmospheres low in oxygen. In fact, it is typical of such atmospheres that little warning is given of their great danger. In some cases men who have collapsed and been rescued have been days recovering. The after effects are very similar to those produced by poisoning by carbon monoxide.

COMPARISON BETWEEN THE INDICATIONS AFFORDED BY CANDLE AND BY ACETYLENE FLAME AND ANALYSES OF THE SAMPLES.

At each place where samples were collected by one of the authors he made a note of the condition of his lamp flames, both candle and acetylene. It is interesting to compare these observations with the oxygen percentages of the various samples, as in the following table:

Data showing relation of oxygen contents of samples to burning of candle and acetylene lamp flames.

MIDGET MINE.

Sample No.	Oxygen in sample.	Candle burned.	Acetylene lamp burned.	Sample No.	Oxygen in sample.	Candle burned.	Acetylene lamp burned.
	Per cent.				*Per cent.*		
781	16.57	No	No.	400	10.86	No	No.
776	18.92	Yes	Yes.	794	11.63	No	No.
770	10.86	No	No.	664	15.06	No	Yes.
296	18.53	Yes [a]	Yes.				

ANACONDA MINE.

Sample No.	Oxygen in sample.	Candle burned.	Acetylene lamp burned.	Sample No.	Oxygen in sample.	Candle burned.	Acetylene lamp burned.
966	7.50	No	No.	694	18.30	Yes [a]	Yes.
937	11.78	No	No.	948	18.44	Yes [a]	Yes.
691	5.51	No	No.	690	17.70	Yes [a]	Yes.
750	7.19	No	No.				

MARY McKINNEY MINE.

Sample No.	Oxygen in sample.	Candle burned.	Acetylene lamp burned.	Sample No.	Oxygen in sample.	Candle burned.	Acetylene lamp burned.
761	10.70	No	No.	780	13.87	No	Yes.
762	8.01	No	No.	976	10.71	No	No.

CRESSON MINE.

Sample No.	Oxygen in sample.	Candle burned.	Acetylene lamp burned.	Sample No.	Oxygen in sample.	Candle burned.	Acetylene lamp burned.
797	7.03	No	No.	754	14.05	No	Yes.
795	16.23	No	Yes.	753	16.74	No	Yes.
760	21.69	No	No.	772	16.65	No	Yes.
759	17.19	Yes [a]	Yes.	944	17.78	Yes [a]	Yes.

[a] Feebly.

In general these results show that the candle flame became extinguished when the oxygen in the atmosphere fell to 17 to 18 per cent, and that the carbide flame was extinguished when the oxygen content fell to 12 to 14 per cent.

COMBUSTIBLE GAS IN THE ROCK-STRATA GAS.

Eight of the samples examined contained traces of combustible gas. The largest proportion was 0.03 per cent. Presumably all of the samples contained small proportions that could not be detected by analysis. The relation between the contraction and the carbon dioxide content indicated that this combustible gas was methane.

Rarely a small outburst of gas is encountered that burns when a torch is applied to it, but quickly burns itself out.

VENTILATION CONDITIONS OF 15 METAL MINES AS INDICATED BY ANALYSES OF AIR SAMPLES.

In Table 9 following are shown data regarding samples of air collected in 15 metal mines. Most of the samples were collected by H. M. Wolflin, mining engineer of the Bureau of Mines. Some were collected by Edwin Higgins, also a mining engineer of the Bureau. The samples were analyzed by the authors. The table and the comments following touch upon the ventilation in the different mines.

Calculations to show the amount of black-damp present were made only for samples that were not affected by blasting operations in the mines.

TABLE 9.—*Data regarding samples of air collected in certain metal mines.*

MINE 1, TONOPAH, NEV.

Lab. No.	Place of sampling.	Temperature.		Relative humidity.	CO_2	O_2	N_2	Black damp.			Composition of black damp.		Remarks.
		Wet-bulb.	Dry-bulb.					CO_2	N_2	CO_2+N_2	CO_2	N_2	
		° *F.*	° *F.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	
4595	West drift, 1,100-foot level	73	84	61	0.05	20.80	79.15	......	......	......	......	......	Blasted 3.15 a. m.; sampled 10 a. m.
4596	Face of east drift, 1,200-foot level	87.5	90	91	.11	20.65	79.24	......	......	......	......	......	Blasted 3 a. m.; sampled 11.20 a. m.; compressed-air ventilation.
4597	21 raise, off crosscut	87	89	93	.17	20.62	79.21	......	......	......	......	......	Blasted 3.15 a. m.; sampled 9.25 a. m.; crosscut is dead end; one man working.
4598	Shaft, above 900-foot level	......	......	......	.16	20.63	79.21	......	......	......	......	......	Taken about 4 p. m., as collector was going up cage.
4599	East drift, No. 7 raise, 1,300-foot level, fan intake.	......	......	......	.07	20.75	79.18	......	......	......	......	......	Fan was delivering 1,530 cubic feet of air per minute to within 45 feet of face of drift.
4600½	Top of raise, No. 3 east side, 1,400-foot level.	98	99	97	.25	20.68	79.07	......	......	......	......	......	Blasted during night; sampled 9.50 a. m.
4601	Shaft, above 900-foot level	......	......	......	.07	20.70	79.23	......	......	......	......	......	Sampled while coming up on cage 11.40 a. m.
4602	Face of crosscut 1055	78	86	71	.06	20.65	79.29	......	......	......	......	......	Blasted 3 a. m.; pipe from fan delivering 510 cubic feet per minute 45 feet back from face; sampled 8.45 a. m.; fan started 7 a. m.
4604	Face of east drift, 400-foot level	90	95	83	......	......	......	......	......	......	......	......	Blasted during night; sampled 10.05 a. m.; temperature of water at sampling place, 101° F.; fan pipe discharging 514 cubic feet of air per minute 20 feet back from face; compressed air also blowing one-half force from ½-inch nozzle. Broken in transit.
4605	Face of east drift, 1,400-foot level (air from fan pipe).	82	92	66	.10	20.58	79.32	......	......	......	......	......	Air from fan pipe discharged 20 feet from face.
4606	Face of east drift, shaft vein, off crosscut, 1,200-foot level.	87	89	93	.04	20.84	79.12	......	......	......	......	......	Blasted during night; sampled 11.40 a. m.
4609	Face of west drift, off crosscut, 1,200-foot level.	85	91	79	1.37	18.49	80.14	......	......	......	......	......	Blasted 3 a. m.; sampled 1.50 p. m., after place had been mucked out; only ventilation from compressed air.
4610	Face of east drift, on 1,300-foot level	88	95.5	76	.24	20.06	79.70	......	......	......	......	......	Sampled 8.15 a. m.; blasted 3 a. m.; men came to work 7 a. m.; end of pipe from fan, 45 feet back from face.
4611	20 feet above sill at top of raise, west drift, shaft vein, off north crosscut, 1,166-foot level.	90	93	89	.31	19.91	79.78	......	......	......	......	......	Sampled 10.45 a. m.; blasted 2.30 a. m.; no ventilation but compressed air; one man shoveling.
4613	Intake of fan, raise, east drift, 1,300-foot level.	81	90	69	.12	20.30	79.58	......	......	......	......	......	Sampled 8.10 a. m.; blasted during night at 3 a. m.; fan set so as to send the same air to the face repeatedly.

4614	Face, No. 7 crosscut, east drift, 1,300-foot level.	84	89.5	81	.27	20.06	79.67						Sampled 8.40 a. m.; blasted between 12 and 3 a. m.; 30 feet ahead of ventilation; only ventilation from 1-inch compressed-air pipe running one-eighth force, 20 feet back from face.
4615	Top of raise 11, 25 feet above sill; shaft vein, west drift, off northeast crosscut, 1,166-foot level.	91.5	93	95	.66	19.68	79.66						Only ventilation from compressed air.

MINE 2, KELLOGG, IDAHO.

4036	Return from stope, near capping station.				1.55	19.44	79.01						Powder smoke rather thick.
4037	do		81		1.58	19.20	79.22						Considerable smoke, most of it from powder; velocity, 200; area, 6.9 by 6.6; 9,100 cubic feet of air per minute.
4038	Top floor of stope		81										One man working Waugh stoping drill about 40 feet away; sample lost.
4039	Top of bench raise		64		.61	20.10	79.29						Two Waugh stopers had been going 35 minutes; four men working; very dusty.
4040	Main return, tunnel		56										Velocity, 655; area, 4.8 by 7.1; air, 22,300; sampled 5 p. m.
4041	do		56		.06	20.84	79.10						Velocity, 643; area, 4.8 by 7.1; air, 21,930; sampled 5.30 p. m.
4042	Return air, tunnel		56		1.41	19.53	79.06						Velocity, 655; area, 4.8 by 7.1; air, 22,300; sampled 4.30 p. m.
4043	do		56										Velocity, 655; area, 4.8 by 7.1; air, 22,300; part of air came from another mine.
4044	Crosscut, thirteenth level												Sampled at beginning of day shift; ventilation entirely dependent on compressed air.
4045	do		66		.25	20.73	79.03						Sampled 6.25 p. m.; no compressor running; blasted at 4 p. m.
4050	Thirteenth level, face of first drift right, leaving shaft.		66		.23	20.63	79.14						Sampled 7.20 p. m.; no air running; blasted 4 p. m.; air probably turned on and let run half force from 4 to 7 p. m.
4052	Return from stope, near capping station.				1.49	19.29	79.22						Smoke, apparently from fuse.
4053	Intake of No. 2 shaft		54		.38	20.59	79.03						Velocity, 225[a]; area, 6.5 by 6.2[b]; air, 9,050[c]; 30 to 35 men work in this current before it reaches point of sampling.
4054	Breast of raise from twelfth level		64		.49	20.30	79.21						Small shot fired 12.30 p. m.; sampled 2.20 p. m.; only ventilation from compressed air; not running at time of sampling.
4055	Face of drift on twelfth level, near floor.		66		1.20	19.70	79.10						Sampled 7.10 p. m.; round of holes fired 4 p. m.; air running about one-fourth to one-half force.
4056	Return from stope, near capping station.				1.59	19.30	79.11						Sampled at 5.30 p. m.; not as much smoke as at 5 p. m.; may be going down shaft.

[a] Velocity of air current in feet per minute.

[b] Feet.

[c] Volume of air current in cubic feet per minute.

TABLE 9.—*Data regarding samples of air collected in certain metal mines*—Continued.

MINE 2, KELLOGG, IDAHO—Continued.

Lab. No.	Place of sampling.	Temperature.		Relative humidity.	CO_2	O_2	N_2	Black damp.			Composition of black damp.		Remarks.
		Wet-bulb.	Dry-bulb.					CO_2	N_2	CO_2+N_2	CO_2	N_2	
		° *F.*	° *F.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	
4077	Top of raise	......	66	......	0.75	16.43	82.82	......	......	......	......	......	Velocity, 310; area, 3.8 by 5.1; air, 6,000; 60 men working below.
4078	Stope near bottom of raise	......	84	......	.30	20.17	79.53	0.27	3.37	3.64	7.4	92.6	Humidity, nearly 100 per cent; dead end, one man working in this place.
4079	....do	......	81	......	.13	20.53	79.34	.10	1.82	1.92	5.2	94.8	Humidity, nearly 100 per cent; dead end, one man working in this place.

MINE 3, BUTTE, MONT.

Lab. No.	Place of sampling.	Wet-bulb.	Dry-bulb.	Relative humidity.	CO_2	O_2	N_2	Black damp CO_2	Black damp N_2	Black damp CO_2+N_2	Composition CO_2	Composition N_2	Remarks.
4099	Return to shaft, south side	81	85	96	.29	20.21	79.50	.26	3.19	3.45	7.5	92.5	Velocity, 260; area, 4.40 by 6.5; air, 7,440.
4098	1675 crosscut, return to shaft	78.5	80	94	.44	20.02	79.54	.41	3.94	4.35	9.4	90.6	Velocity, 490; area, 3 by 6.1; air, 8,950; sampled, 9.45 a. m.; this is main return to shaft from north side on 1,600 level.
4102	2410 stope, sixth floor	83.5	84.5	96	.29	20.26	79.45	.26	2.95	3.21	8.1	91.9	Raise through but no air circulating.
4103	2801 crosscut, 100 feet north of vein A	89.5	90.5	96	.19	20.52	79.29	.16	1.81	1.97	8.1	91.9	Only ventilation in this crosscut was from one air drill 700 feet away.
4104	2118–C raise, eleventh floor	83	85	92	.31	20.41	79.28	.28	2.21	2.49	11.2	88.8	Sampled, 10 a. m.; blasted, 2 a. m.; air running on tenth floor of raise after blasting; only ventilation, compressed air.
4105	1601 crosscut, at vein near stable	75	75.5	98	.06	20.84	79.10	.03	.41	.44	6.8	93.2	Velocity, 165; area, 3.9 by 5.9; air, 3,560; part of main return on 1,600 level.
4106	2402–C drift, near face	83	84	96	.18	20.67	79.15	.15	1.10	1.25	12.0	88.0	Only ventilation, compressed air; shot at 2 a. m.; no air turned on till 8.45 a. m., when full head was turned on; sampled, 9.10 a. m., when air felt better near face than back in drift.
4107	Shaft between 400-foot and 800-foot levels.	......	......	......	......	......	......	......	......	......	......	......	Sample taken from cage at 9.30 a. m. before rock-hoisting started.
4108	Return from 2252–C raise, at 2000 level.	76	76.5	98	......	......	......	......	......	......	......	......	
4109	Shaft above 700 level, from cage after passing 700-foot level going to surface.	76	76	100	.10	20.29	79.61	......	......	......	......	......	Sampled at noon.
4110	Face of 2601 drift	84.5	87	90	.09	20.58	79.33	......	......	......	......	......	Sampled at 11.15 a. m.; round blasted in face at 2 a. m.; point of sampling 300 to 400 feet ahead of air; two compressed-air hoses blowing air into or near face.

MINE 4, BUTTE, MONT.

4100	1206 crosscut, 150 feet from 1201 crosscut, at fire wall.	92.5	108.5	60	.42	19.76	79.82	......	......	......	......	......	Velocity, 775; area, 1 foot 8 inches by 4 feet 7 inches; air, 6,300; respiration labored where sample was taken.
4101	Third floor of stope 1869	79	81.5	90	.35	20.26	79.39	.32	2.89	3.21	10.0	90.0	Floor is 3 sets long and 1 set wide; no raise through to next level.
4096	1200 station of No. 1 shaft	84	88	85	.23	20.40	79.37	.20	2.34	2.54	7.9	92.1	
4097	1260 station near junction 1284, return to air shaft.	91.5	96	84.5	.27	20.10	79.63	.24	3.73	3.97	6.0	94.0	Velocity, 1,040; area, 3 feet 10 inches by 6 feet 9 inches; air, 27,200; part of air went through pump room on the 1,200, remainder came up from 1300.
4282	First floor of 1491 stope	87.5	88.5	96	.18	20.19	79.63	.15	3.39	3.54	4.2	95.8	Only ventilation, compressed air.
4283	Twenty-second floor of stope 1637	86	87	96	.07	20.85	79.08	.04	.35	.39	10.2	89.8	Raise was holed at time of sampling; circulation marked.
4285	Top of fourth floor of 1492 raise	85	87.5	92	.19	20.23	79.58	.16	3.19	3.35	4.8	95.2	Ventilation, compressed air only.
4286	Sixth floor of stope 1477	88	89	96	.15	20.47	79.38	.12	2.08	2.20	5.5	94.5	Two repair men had just left place when sample was taken.
4224	1414, 10 feet north of stope 1450	84	85	96	.11	20.41	79.48	.08	2.41	2.49	3.2	96.8	1414 is air course on 1400; sample taken where air goes into shaft to return to surface.
4225	On 1409 drift at 1453 chute	82.5	83.5	96	.15	20.36	79.49	.12	2.61	2.73	4.4	95.6	Velocity, 190; area, 3.8 by 6.7; air, 4,080; air returning to No. 1 shaft.
4227	Second floor of stope 1678	81	81.25	99	.60	19.73	79.67	.57	5.17	5.74	9.9	90.1	Two men working in stope near raise which is holed through.
4229	1900 level, about 86 feet from No. 1 shaft	85.5	87	94	.09	20.86	79.05	.06	.28	.34	17.6	82.4	Only ventilation, compressed air, which was running about three-fourths force until two minutes before sample was taken.
4230	Breast of 2007 drift	89.5	90	98	.17	20.55	79.28	.14	1.68	1.82	7.7	92.3	Dead end.
4231	Outlet of main fan, at surface	87	89	92	.22	20.41	79.37	.19	2.30	2.49	7.6	92.4	
4232	Eighteenth floor of 1641 stope	87	88	.....	.13	20.48	79.39	.10	2.07	2.17	4.6	95.4	One man working 30 feet from raise which was holed through.

MINE 5, BUTTE, MONT.

4141	Second floor of stope 2390	78	80	92	0.07	20.92	79.01	......	......	......	......	......	One man running drill (stoper) on third floor near where sample was taken.
4142	Sill floor of stope 2326 (survey point 92).	85.5	86	99	.14	20.73	79.13	......	......	......	......	......	Rather hot; not much air moving, owing to recent blocking of air raise.
4143	Face of 2880 drift, 125 feet west of 2886	90	91	96	.17	20.79	79.04	......	......	......	......	......	Two 1-inch hose, 30 feet apart, discharging air into place, turned on one-fourth to one-half force; sample taken halfway between them; blasted 2 a. m.; sampled 3 p. m.
4144	Station of 3000 level	81	82	96	.16	20.71	79.13	......	......	......	......	......	Ventilation by compressed air only; blasted 8 a. m.; sampled 3.40 p. m.
4145	Fan conduit	75	75.5	98	.21	20.57	79.22	0.18	1.55	1.73	10.4	89.6	Velocity, 1025; area, 7 by 4.7; air, 33,650.
4146	2017 raise on 1900	86	86	100	.35	20.36	79.29	.32	2.41	2.73	11.7	88.3	Velocity, 245; area, 9 by 4.2; air, 9,800.
4147	1900 water crosscut, west of 2017	85	88	89	.33	20.42	79.25	.30	2.14	2.44	12.3	87.7	Face is in old worked out and filled stope; compressed air turned on about one-fourth force, 10 feet back from face.
4148	Breast of stope, twelfth floor, 10 sets east of 2270 raise.	70	72.5	89	.07	20.87	79.06	.04	.25	.29	13.8	86.2	

TABLE 9.—*Data regarding samples of air collected in certain metal mines*—Continued.

MINE 5, BUTTE, MONT.—Continued.

Lab. No.	Place of sampling.	Temperature.		Relative humidity.	CO_2	O_2	N_2	Black damp.			Composition of black damp.		Remarks.
		Wet-bulb.	Dry-bulb.					CO_2	N_2	CO_2+N_2	CO_2	N_2	
		° *F.*	° *F.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	
4149	Breast of stope, 2 sets east of 2809 raise.	90	91	96	0.12	20.72	79.16	.09	.92	1.01	8.9	91.1	Sampled 2.35 p. m.; blasted on previous shift, 2 a. m.; compressed air running one-third force; no drilling going on.
4152	Face of drift 2825	90	91	96	.13	20.69	79.18	.10	1.05	1.15	8.7	91.3	Compressed air running one-fourth force until 1 minute before sample was taken; pipe delivering 1,720 cubic feet of air per minute 75 feet back from face; place very wet; temperature of water, 100° F.
4153	Raise short distance below fan	78	78	100	.26	20.36	79.38	.23	2.50	2.73	8.4	91.6	Total air up raise, 41,184 cubic feet per minute.
4154	2444 on 2200 level	82.5	86	87	.17	20.73	79.10	.14	.82	.96	14.6	85.4	Total air up raise, 1,740.
4156	Top of 2370 stope	85	86.5	94	.16	20.72	79.12	.13	.88	1.01	12.9	87.1	Air, 2,518.
4157	Top of 2801 raise on 2400 level	83	85	92	.16	20.65	79.19	.13	1.22	1.35	9.6	90.4	Velocity, 347; area, 3 by 1.5; air, 1,560.
4158	Top of 2835 raise	87.5	89	94	.18	20.64	79.18	.15	1.24	1.39	10.8	89.2	Velocity, 270; area, 2.1 by 2.4; air, 1,360; sampled 10.30 a. m.; considerable leakage of air not included in measurement, so actual quantity was larger than one given.
4159	Top of raise 2209	74	77	87	.08	20.83	79.09	.05	.34	.39	12.9	87.1	Velocity, 373; area, 4.1 by 2.2; air, 3,300.
4161	Top of main air raise on 1100 level				.30	20.35	79.35	.27	2.51	2.78	9.7	90.3	Air, 13,405.
4162	Air raise just below 1000 level	80	80	100	.21	20.54	79.25	.18	1.69	1.87	9.6	90.4	Air, 23,600; area much restricted by lagging placed across the raise by repair men.
4163	1000 level, at door near raise	80.5	81	99	.22	20.55	79.23	.19	1.63	1.82	10.4	89.6	Velocity, 1400; area, 3.9 by 2; air, 23,600; part of this air may have been short circuited from surface.
4164	Incline near surface	78	91	57	.13	20.62	79.25	.10	1.39	1.49	6.7	93.3	Sampled in east hoisting department; shaft downcast in two compartments and upcast in two; no "lining boards" between downcast and upcast air; total upcast air, 9,320, and total downcast air, 5,070 cubic feet per minute; temperatures at this point in shaft, 79° to 93° F.; sample of upcast air.
4165	1900 water crosscut, west of 2017				.31	20.49	79.20	.28	1.83	2.11	13.3	86.7	Sampled in caved ground, 15 feet in advance of where men were working; timber badly decayed; compressed air running one-half to one-fourth force, about 25 feet back from where sample was taken.

MINE 6, IRONWOOD, MICH.

4315	No. 9 crosscut, 24 level, 225 feet north of rock drift.	60	61	....	0.14	20.76	79.10	0.11	0.71	0.82	13.4	86.6	Velocity, 450; area, 54: air, 24,300; air passing timbers.
4316	K shaft, 50 feet above 19th level.......	55	57.5	....	.11	20.81	79.08	.08	.50	.58	18.8	86.2	Air, 35,800; air passing timbers.
4317	.....do................................	55	57.5	....	.06	20.81	79.13	.03	.55	.58	5.2	94.8	Do.
4318	Drift, 347 feet west of 168 raise........	61	62	....	.10	20.72	79.18	.07	.94	1.01	......	......	Velocity, 360; area, 42.25; air, 15,210; air passing timbers.
4319	.....do................................	61	62	....	.10	20.77	79.13	.07	.70	.77	9.1	90.9	Velocity, 260; area, 42.25; air, 15,210; air passing timbers.
4320	888 feet west of K shaft, 24 level.......	59	60	....	.10	20.84	79.06	.07	.37	.44	15.9	84.1	Velocity, 600; area, 60; air, 36,000; air passing timbers.
4321	.....do................................	59	60	....	.07	20.78	79.15	.04	.68	.72	5.6	94.4	Do.
4322	Drift, 592 feet west of 168 raise........	61.5	62.5	....	.09	20.76	79.15	.06	.76	.82	7.3	92.7	Velocity, 265; area, 40.3; air, 10,680; air passing timbers.
4323	.....do................................	61.5	62.5	....	.10	20.77	79.13	.07	.70	.77	9.1	90.9	Do.
4324	No. 9 crosscut, 24 level, 225 feet north of rock drift.	60	61	....	.07	20.81	79.12	.04	.54	.58	6.9	93.1	Velocity, 450; area, 54; air, 24,300; air passing timbers.

MINE 7, TROJAN, S. DAK.

4325	Breast of C left stope..................	48	49	94	0.26	20.37	79.37	......	......	......	......	......	Blasted, 5 a. m.; sampled, 2.25 p. m.
4326	Breast of D stope.......................	49	51	88	.38	20.17	79.45	......	......	......	......	......	Blasted, 5 a. m.; sampled at 2.05 p. m.
4327	Breast of C stope.......................	46	47	93	.56	19.88	79.56	......	......	......	......	......	Fired "plug" at noon; little powder smoke in air at time of sampling, 2.15 p. m.
4328	Raise..................................	50	51	94	.46	19.95	79.59	......	......	......	......	......	Shot a "plug" during morning; sampled, 1.40 p. m.
4329	Breast of M stope.......................	48	48.5	97	.20	20.31	79.49	......	......	......	......	......	Blasted around 5 a. m.; sampled, 1.50 p. m.
4343	West crosscut..........................	42	43.5	90	....	....	....	......	......	......	......	......	
4344	Tunnel.................................	42	44	86	.08	20.81	79.11	......	......	......	......	......	Two men in place, one shoveling, one running Leyner drill; blasted in place on previous day shift; sampled, 10.50 a. m.

MINE 8, TROJAN, S. DAK.

4345	Crosscut raise..........................	44	46	87	0.12	20.73	79.15	......	......	......	......	......	Blasted 18 hours before sample was taken; sampled, 10.20 a. m.

MINE 9, TONOPAH, NEV.

4617	Toilet in end of crosscut, south of drift 515, shaft.	....	....	....	0.04	20.88	79.08	......	......	......	......	......	

TABLE 9.—*Data regarding samples of air collected in certain metal mines*—Continued.

MINE 10, TONOPAH, NEV.

Lab. No.	Place of sampling.	Temperature.		Relative humidity.	CO_2	O_2	N_2	Black damp.			Composition of black damp.		Remarks.
		Wet-bulb.	Dry-bulb.					CO_2	N_2	CO_2+N_2	CO_2	N_2	
		° *F.*	° *F.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	
4624	Face of 1003 drift west	75	80	80	0.09	20.63	79.28	......	......	......	......	......	Slight odor of powder gas.
4625	Face of 1018 south crosscut, 30 feet from 1003 west drift.	77	80	88	.14	20.74	79.12	......	......	......	......	......	Blasted, 11 p. m.; sampled, 8.45 a. m.; fan shut off during night; fan, 7 a. m.; fan delivering 855 cubic feet per minute almost 100 feet back from face.
4627	1,000-foot level station	77	78	96	.13	20.70	79.17	0.10	1.01	1.11	9.0	91.0	885 cubic feet of air per minute from fan pipe must have been passing here.

MINE 11, LEAD, S. DAK.

Lab. No.	Place of sampling.	Wet-bulb.	Dry-bulb.	Relative humidity.	CO_2	O_2	N_2	Black damp CO_2	Black damp N_2	Black damp CO_2+N_2	Composition CO_2	Composition N_2	Remarks.
4421	Face of No. 12 west crosscut on 1,700-foot level.	61	62.5	92	0.12	20.71	79.17	0.09	0.97	1.06	8.5	91.5	Dead end; only ventilation is from compressed air.
4422	Footwall west of mule chute on 200-foot level.	78.5	80	94	.38	20.43	79.19	.35	2.05	2.40	......	......	
4423	Hanging-wall header east of 13,200-foot level.	66	66.5	98	.20	20.68	79.12	.17	1.03	1.20	14.2	85.8	Return air; most of it from No. 4 and No. 6 districts of 300-foot level; perceptible current, but not enough to allow velocity to be measured.
4424	Sill floor, 16 stope south on 1,700-foot level.	61.5	62.5	95	.22	20.74	79.04	......	......	......	......	......	Considerable powder smoke.
4425	Sill floor 4 west, vertical stope, 400-foot level.	79	82	88	.31	20.21	79.48	......	......	......	......	......	Considerable powder smoke; good current of air; powder smoke lifted quickly and air was clear short time after sample was taken.
4426	Second floor, fourth northwest stope, 500-foot level.	71	73	91	.24	20.40	79.36	.21	2.33	2.54	8.2	91.8	Raise caved and blocked; not much air circulating.
4427	Mule chute on 300-foot level	78	80	92	.30	20.26	79.44	.27	2.94	3.21	8.4	91.6	Drawing ore from chute; no air circulating.
4428	Sixth floor, sixth northwest stope, 500-foot level.	86	89	89	.23	20.28	79.49	.20	2.91	3.11	6.5	93.5	Only ventilation from compressed air; timbers badly crushed; odor of decayed timber.
4429	Footwall drift, off southwest stope of 300-foot level.	67	67	100	.25	20.38	79.37	......	......	......	......	......	Air foggy.
4431	No. 5 stope on 1,000-foot level	59	60	95	.10	20.46	79.44	......	......	......	......	......	Some powder smoke noticeable in air.
4432	No. 5 stope, 500-foot level, on hanging-wall side where waste was being dumped.	55.5	56.5	94	.17	20.57	79.26	......	......	......	......	......	

4433	No. 3 south on 1,250-foot level	58	58.5	97	.09	20.69	79.22	......	......	......	......	......	Not taken in dead end; considerable air was moving through drift at time of sampling, but it contained some powder smoke from block holing.
4434	Drift in No. 3 north of vertical stope, 400-foot level.	78.5	82	86	.31	20.47	79.19	.31	1.90	2.21	14.0	86.0	Ground caved.
4435	1,000-foot level at top raise from No. 6 stope, east 1100.	58	59	95	.13	20.39	79.48	......	......	......	......	......	Considerable powder smoke from block holing.
4436	Eighth floor, No. 9 stope, 1,250-foot level.	59.5	60.5	95	.19	20.50	79.31	.16	1.91	2.07	7.7	92.3	Two men working with drill on top of broken rock at 8.30 a. m.
4437	Sill floor, stope 2, 500-foot level	59	60	95	.10	20.61	79.29	......	......	......	......	......	Twelve men working with carbide lamps at point where sample was taken; sample taken just before men returned to work after firing 17 block holes; smoke cleared rapidly.
4438	Second floor, No. 4 west vertical stope, 400-foot level.	100.5	101.5	97	1.11	19.24	79.65	1.08	7.00	8.08	13.4	86.6	Beads of moisture hanging on timbers; sampled 11.40 a. m.
4439	Ninth floor, No. 3 north center stope, 600-foot level.	75	79	84	.10	20.61	79.29	......	......	......	......	......	Country badly crushed; dead end; odor of decaying timber.
4441	Shaft header, 600 feet from face, 1,700-foot level.	61	62	95	.20	20.59	79.21	......	......	......	......	......	Sample taken in shaft header where powder smoke was thickest.
4442	Fifth floor, No. 2 north stope, 600-foot level.	75	79	84	.20	20.43	79.37	.17	2.23	2.40	7.1	92.9	Crushed country; odor of decaying timber.
4443	Fifth floor, No. 2 west stope, 600-foot level.	76	78	92	.19	20.44	79.37	.16	2.19	2.35	6.8	93.2	Two had been drilling shortly before sample was taken.
	MINE 12, VETERAN, NEV.												
4458	Small raise (No. 3) near breast of No. 59 drift.	85	88	89	0.47	19.88	79.65	0.44	4.58	5.02	8.8	91.2	Sampled after raise had been connected with sublevel.
4459	Inby toilet boxes	64	65	95	.43	20.11	79.46	.40	3.52	3.92	10.2	89.8	
4460	Bottom 40 winze where drift was being widened.	64	66.5	89	.61	20.16	79.23	.58	3.11	3.69	15.7	84.3	Not a dead end; connection had been made for ventilation.
4461	Return air at main shaft	64	67	86	.69	19.93	79.38	.66	4.12	4.78	13.8	86.2	Fairly strong current of air, but velocity not great enough in large area to allow measurement.
4462	Face 34 winze incline	73	76	78	1.04	19.37	79.59	......	......	......	......	......	Blasted on night shift; 8-inch air pipe connected to fan is delivering 114 cubic feet of air per minute 25 feet back from face.
4463	Near bottom of drill hole for suction fan.	67	68	95	1.10	18.77	80.13	1.07	9.25	10.32	10.4	89.6	Velocity, 702; area, 1.9 by 2.15; air, 2,870.
4464	In 85 sublevel just above 59 (No. 3 raise).	......	......	......	1.22	18.34	80.44	......	......	......	......	......	Blasted, 11.25 a. m.
4465	Face of No. 37 drift (retreating)	78	81	88	.32	20.38	79.30	......	......	......	......	......	Blasted about midnight; compressed air blowing one-eighth force.
4466	Small raise (No. 3) near breast of 59 drift.	93	98	83	.71	19.30	79.99	.68	7.11	7.79	8.7	91.3	Sample taken 1 inch from top of raise; candle extinguished at top; blasted on night shift; sampled 8.55 a. m.; one man working in raise.
4467	Face of sublevel 55	......	......	......	.84	19.54	79.62	......	......	......	......	......	Sampled, 12.35 p. m.; blasted, 11.30 a. m.
4468	Crosscut 4	76	78	92	.57	20.06	79.37	.54	3.62	4.16	13.0	87.0	Timberman blasted a small "plug" about 15 minutes before sample was taken and turned on compressed air; returned to work and turned off air just before sample was taken.

TABLE 9.—*Data regarding samples of air collected in certain metal mines*—Continued.

MINE 12, VETERAN, NEV.—Continued.

Lab. No.	Place of sampling.	Temperature.		Relative humidity.	CO_2	O_2	N_2	Black damp.			Composition of black damp.		Remarks.
		Wet-bulb.	Dry-bulb.					CO_2	N_2	CO_2+N_2	CO_2	N_2	
		° *F.*	° *F.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	
4469	Mule barn	73	77	83	0.83	19.77	79.40	.80	4.75	5.55	14.4	85.6	8-inch pipe connected to fan delivering about 483 cubic feet of air per minute in the barn.
4470	West drift (30 raise)	69	71	91	.76	19.81	79.43	......	......	......	......	......	Dead end; blasted on night shift; sampled, 10.20 a. m.
4471	Face of No. 85 sublevel, east end	83	87	......	.62	19.73	79.65	......	......	......	......	......	Blasted on night shift; 8-inch pipe delivering 127 cubic feet of air per minute 15 feet back from face; air had a temperature of 84° F. and a relative humidity of 72 per cent; sampled, 9.40 a. m.
4472	Near face of No. 85 sublevel, west end	85	88	89	.60	19.77	79.63	......	......	......	......	......	Blasted here previous night; sampled 9.20 a. m.; one man hand drilling near face; 8-inch pipe from fan delivering 56 cubic feet of air per minute a short distance back from face.
4473	South end of 17 winze	70.5	71.5	95	1.17	18.85	79.98	......	......	......	......	......	Sampled 2.10 p. m.; blasted one little plug after noon; no big blast after previous night shift.
4474	Sixth crossent through pillar	76	80	84	.79	19.75	79.46	.76	4.88	5.64	13.5	86.5	Did not blast on night shift; candle burned fairly well; sampled 8.30 a. m.
4475	East end of No. 73 sublevel	74	77.5	94	.30	20.40	79.30	......	......	6.74	8.6	91.4	Sampled 10.20 a. m., 15 minutes after blasting one-half stick powder; 8½-inch pipe connected to fan discharging 113 cubic feet of air per minute 15 feet back from face.
4476	East end of sublevel 73, near raise 55	73	75	91	.67	20.92	78.41	......	......	......	......	......	Sampled 10.50 a. m.; blasted on night shift; 8½-inch pipe connected to fan is discharging 139 cubic feet of air per minute 40 feet back from face.
4477	Near face of No. 59 drift (retreating)	84	89	82	.61	19.52	79.87	.58	6.16	6.74	8.6	91.4	Did not blast till night shift; end of 8-inch pipe from fan is about 10 feet from where man is working; pipe is discharging 200 cubic feet of air per minute, which has a temperature of 87° F. and a relative humidity of 65 per cent; sampled at 9.05 a. m.
4478	Face of sublevel 65, west side	70	72	91	.92	19.05	80.03	......	......	......	......	......	Blasted 12 sticks at 11.30 a. m.; sampled 12.45 p. m.
4479	Sublevel 65, east side	67	69	91	.94	19.11	79.95	......	......	......	......	......	Blasted 12 sticks 11.30 a. m.; sampled 12.50 p. m.
4540	Second sublevel above 13th level, between chutes 50 and 51.	79	80	......	(1)	......	......	......	......	......	......	......	Much powder smoke.
4541	....do	79	80	......	(1)	......	......	......	......	......	......	......	Do.
4542	Face east cave, over 45 chute, 12th level.	76	79	......	.73	20.17	79.10	......	......	......	......	......	Before blasting.
4543	....do	76	79	......	.71	20.14	79.15	......	......	......	......	......	Do.

4544	Mouth of cave in 45 chute, 12th level (1¼ hours after blast).	75	75		(1)								Some powder smoke.
4545	.....do	75	75		(1)								Do.
4548	50 feet below collar B shaft (upcast)	61	61		.26	20.68	79.06						
4549	.....do	61	61		.28	20.68	79.04						

MINE 13, TONOPAH NEV.

4799	Face 409 south crosscut	68	71	81	.15	20.70	79.15						Blasted 3.15 p. m.; turned on compressed air at 6.15 p. m.; ½-inch nozzle almost full force; 90 pounds air pressure at compressor; sampled 7.25 p. m.; dead end.
4800	3 west drift, off 3 south crosscut, 500-foot level.	65	70	78	.04	20.91	79.05						Dead end; blasted 3.15 p. m.; air (compressed) ran for 1 hour; half force from ½-inch nozzle; sampled 8 p. m.
4801	Top of 610 raise	71	73	91	.42	20.44	79.14	.39	1.96	2.35	16.5	83.5	Dead end; air drills run one shift after blasting; sampled 9.15 p. m.; odor of powder gas; only ventilation from compressed air; stoping drills with sprays used to allay dust.
4802	605 east drift	63	66	86	.06	20.79	79.15	.03	.65	.68	4.4	95.6	Sampled 8.10 p m.; blasted 3.15 p. m.; not exactly a dead end, but connection not arranged to give best ventilation.
4803	No. 1 stope, 500-foot level	68.5	69.5	95	.10	20.73	79.17						Blasted 3.15 p. m.; sampled 8.30 p. m.; not a "tight end."
4804	Compressed air from face, 409 south crosscut.				.06	20.88	79.06	.03	.22	.25	12.0	88.0	Sample of compressed air taken 7.25 p. m.
4805	No. 1 shaft above 400-foot level				.08	20.80	79.12						Return air from No. 1 shaft; sampled 7.10 p. m.; blasted 3.15 p. m.
4806	Face 606, intermediate level	64	69	78	.13	20.69	79.18						Dead end; odor of powder gas; no smoke visible; blasted 2.15 a. m.; sampled 8.20 p. m.
4807	602 east heading	61	79	34	.13	20.72	79.15						Blasted 3.15 p. m.; sampled 8.55 p. m.
4808	Face No. 3 south crosscut, 600-foot level	65	70	78	.06	20.80	79.14						Dead end; sampled over muck pile at 9 p. m.; blasted 3.15 p. m.
4809	610 raise	69	73	83	.20	20.69	79.11						Dead end; blasted 3.15 p. m.; sampled 9.35 p. m.

MINE 14, TONOPAH, NEV.

4810	422 east drift (face)	70	73	87	.18	20.64	79.18						Dead end; air drill running for 1 hour; blasted on night shift; sampled at 10.30 a. m.
4811	No. 322 crosscut	71	73	91	.22	20.62	79.16						Dead end; sampled 9.30 a. m.; over a muck pile just back from face; blasted at 2.20 a. m.; only ventilation from compressed air running about one-half hour after blast and then 1 to 1½ hours before the next shift starts work; air drill running at time sample was taken.
4812	No. 24 raise, 565-foot intermediate level.	74	77	87	.52	20.32	79.16						Blasted 3.30 p. m.; sampled at 10.15 a. m.; one man running Waugh air drill; ventilation connection not very good.

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[1] No sample.

TABLE 9.—*Data regarding samples of air collected in certain metal mines*—Continued.

MINE 14, TONOPAH, NEV.—Continued.

Lab. No.	Place of sampling.	Temperature.		Relative humidity.	CO_2	O_2	N_2	Black damp.			Composition of black damp.		Remarks.
		Wet-bulb.	Dry-bulb.					CO_2	N_2	CO_2+N_2	CO_2	N_2	
		° *F.*	° *F.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	
4813	No. 24 east drift, 565-foot intermediate level.	72	73	91	.30	20.54	79.16	.27	1.60	1.87	14.5	85.5	
4814	Top raise, 465-foot level	69	70	95	.04	20.91	79.05	......	......	......	......	......	This air is coming from lower levels; sampled 8.50 a. m.
4815	Air receiver on 615-foot level	......	......	......	.05	20.93	79.02	......	......	......	......	......	Sample of compressed air taken at underground receiver; no compressor or receiver explosions in this mine.
4816	20 intermediate stope, 565-foot level	74	77.5	86	.36	20.39	79.25	......	......	......	......	......	Blasted 3.20 p. m.; sampled 10 a. m.; one man drilling, using a Waugh machine requiring about 44 cubic feet of air at pressure of 85 pounds.
4817	West end of vein near face, crosscut 628, cutting stope.	62	65	86	.14	20.61	79.25	.11	1.43	1.54	7.1	92.9	Sample taken near where timbermen were working inside of where air was blowing.

MINE 15, TONOPAH, NEV.

Lab. No.	Place of sampling.	Wet-bulb.	Dry-bulb.	Relative humidity.	CO_2	O_2	N_2	Black damp CO_2	Black damp N_2	Black damp CO_2+N_2	Composition CO_2	Composition N_2	Remarks.
4768	600–C stope	58	71½	48	0.06	20.36	79.58	......	......	......	......	......	Blasted 2.20 a. m.; sampled 8.30 a. m.; stope connected, not a dead end.
4769	501 hangingwall crosscut	46	58½	41	.07	20.35	79.58	......	......	......	......	......	Blasted 3.20 p. m.; sampled 8.40 a. m.; very dusty.
4770	Intake of fan on 600-foot level	......	......	......	.09	20.81	79.10	......	......	......	......	......	No. 2½ Sirocco fan so set that some chance for air to be sent to working place more than once; arrangement temporary; sending 1,600 cubic feet of air per minute through fan wheel.
4771	Top raise 662	76	79½	88	.33	20.36	79.31	......	......	......	......	......	Dead end; blasted 3.20 p. m.; sampled 10.36 a. m.; end of ventilating pipe 50 feet down raise and plenty of pipe on the level for miner to bring air to working place; pipe delivered 635 cubic feet of air per minute,
4772	602 drift, about 20 feet ahead of air pipe.	74	78½	84	.10	20.67	79.23	.07	1.18	1.25	5.6	94.4	Dead end; men were working 20 feet ahead of air pipe. delivering 640 cubic feet of air per minute; had not blasted for a day or two.
4773	In main shaft, above the 400-foot level	......	......	......	.08	20.73	79.19	.05	.91	9.6	5.2	9	Sampled while coming up on cage.
4774	601 winze	63	72.5	61	.07	20.78	79.14	......	......	......	......	......	Blasted 3.20 p. m.; sampled 9 a. m.; dead end, 40 feet down a winze; only ventilation from compressed air.
4775	Raise 548 west	71	71	100	.71	17.77	81.52	.68	14.42	15.10	4.5	95.5	Candle was extinguished where sample was taken; may have a little gas from strata.

4776	70 feet from top of 641 raise	73	74	96	.29	20.56	79.15	......	......	......	......	......	Two raises come together here; no connection through for ventilation; dead end; blasted 3.20 p. m.; sampled 9.30 a. m.
4777	600 east stope	74	75	96	.14	20.74	79.12	......	......	......	......	......	Dead end; blasted in raise nearby, 2.20 a. m; blasted here at 3.20 a. m.; sample taken at 9.10 a. m.
4778	Compressed-air sample	......	......	......	.06	20.91	79.03	......	......	......	......	......	Sample taken on the surface about 3.50 p. m.
4779	Top of 669 raise	76	78	92	.16	20.58	79.26	.13	1.55	1.68	7.7	92.3	Dead end; man had not worked here for a week; only ventilation from compressed air; man just starting to work when sample was taken.

COMMENTS ON RESULTS OF ANALYSIS.

Only one of the samples (laboratory No. 4609) of air from Mine 1 contained a proportion of oxygen that was either low or excessive as compared with the oxygen content of ordinary air. All of the samples were collected several hours after blasting operations. Hence the mine air was not vitiated in any appreciable degree at the time the samples were collected. All of the temperatures observed at the time of sampling were high—too high to allow men to do good work.

Of the samples collected in Mine 2, four (laboratory Nos. 4036, 4037, 4052, and 4056) contained excessive amounts of carbon dioxide. These samples were all collected at the same place, a few minutes apart. The atmosphere contained powder smoke as the result of a previous blast, hence the atmosphere was vitiated by products of combustion from the blast. Wet-bulb temperatures were not noted in this mine. The dry-bulb temperatures were good except that observed at the time of taking the sample designated laboratory No. 4079. The wet-bulb temperature was not determined in connection with the collection of this latter sample, but the sense of discomfort experienced by the sampler and the moist condition of the place of sampling indicated that the air was almost saturated with moisture. Sample 4079 was the only one, not contaminated with products of combustion from a blast, that had a high percentage of carbon dioxide. The analyses of two of the samples collected in Mine 2 were recalculated to show the percentage of black damp present.

Wet-bulb temperatures observed in Mine 3 exceeded 75° F. The chemical analyses disclosed no low oxygen or high carbon dioxide content. The composition of the black damp ranged from 5.2 to 12 per cent carbon dioxide and from 88 to 94.8 per cent oxygen.

The temperatures and the humidity readings observed in Mine 4 were excessively high. The chemical analyses of the air disclosed no bad condition. Black damp contained 4.2 to 17.6 per cent carbon dioxide and 82.4 to 95.8 per cent oxygen.

The temperatures were higher in Mine 5 than is compatible with the best working efficiency. The chemical analyses disclosed no high carbon dioxide or low oxygen percentages. The black damp contained 6.7 to 13.8 per cent carbon dioxide and 86.2 to 93.3 per cent nitrogen.

Favorable temperatures were found in Mines 6, 7, 8, and 9. The chemical analyses of the air also showed good conditions.

Temperatures in Mine 10 were not so good.

Most of the observed temperatures in Mine 11 were good. There was one noteworthy exception, that noted at the time of taking sample 4438. The carbon dioxide content was also high in that sample.

Considerable powder smoke was present at some places where samples were collected, but no carbon monoxide that might have remained in the air after the shooting was found.

Many of the temperatures observed in Mine 12 were low. Some exceeded 75° F., wet bulb. The carbon dioxide and oxygen contents in some of the samples were low, especially in samples 4463, 4464, and 4473. Just how much blasting operations affected these samples is problematical. One sample (No. 4464), collected 11 hours after blasting, contained 1.22 per cent carbon dioxide and 18.34 per cent oxygen. In general the chemical analyses of the samples from Mine 12 disclosed higher carbon dioxide and lower oxygen contents than in the samples from any of the other mines.

The temperatures in Mine 12 were favorable.

The temperatures observed in Mines 14 and 15 were good. Only in Mine 12 were samples collected that contained excessively high percentages of carbon dioxide or excessively low percentages of oxygen.

In summing up conditions in these metal mines it can be said that, as regards the chemical analyses of the samples collected, the air, on the whole, was very good. Samples collected several hours after blasting, and when men were mucking out their places, did not contain carbon monoxide from the blasting operations. Changes in the air of metal mines due to oxidation are not as rapid as in coal mines, in spite of the fact that immense volumes of air sweep through coal mines as compared to metal mines, where the ventilation is natural or where air is supplied from compressed-air lines.

The chief trouble lies in the high temperatures, both wet-bulb and dry-bulb; also, the stagnation of the air encountered in many places is so bad as to be detrimental to the health and to the efficiency of the workmen.

OBSERVATIONS REGARDING BLACK DAMP IN CERTAIN METAL MINES.

The average percentage of black damp in certain mines and the average composition of the black damp are shown in the following table:

Average percentage and average composition of black damp in certain metal mines.

Mine No.	Average per cent of black damp.	Composition of black damp.	
		CO_2.	N_2.
		Per cent.	*Per cent.*
2 and 3	2.52	8.4	91.6
4	2.64	7.4	92.6
5	1.60	10.9	89.1
6	.71	7.9	92.1
11	2.78	9.5	90.5
12	5.76	11.8	88.2

The average of all analyses in the above table is 2.67 per cent black damp with a composition corresponding to 9.3 per cent carbon dioxide and 90.7 per cent nitrogen.

The average composition of black damp in metal mines is about the same as that found in coal mines. A difference in its occurrence in the two kinds of mines lies in the amount that can be produced in a given time.

If coal mines depended only on natural ventilation or on compressed air from pipes at working places, the amount of black damp produced would usually exceed far more than it does that produced in metal mines, for coal reacts with oxygen much more rapidly than do most of the rocks, wood, etc., found in metal mines.

SUMMARY.

The most satisfactory definition of the term "black damp" is an accumulation of carbon dioxide and nitrogen in excess of the percentage found in pure atmospheric air.

The principal factors that affect the changes in mine air are (1) the velocity with which the mine air traverses the mine passages; (2) the amount of coal with which it comes in contact; (3) the gaseous (methane) nature of the seam; (4) the nature of the coal as regards its power to react with oxygen; (5) the temperature and the wetness of the mine.

Carbon dioxide must be present in large proportions before it threatens life. A proportion of 3 to 4 per cent of carbon dioxide in air affects the breathing of most people. Men may, however, work for a long time in such an atmosphere, although their efficiency as workmen will be greatly affected and they will become fatigued quickly. The presence in air of as little as 1 or 2 per cent of carbon dioxide is not so much a matter of safety and comfort to those who breathe it as it is of their efficiency as workmen.

Distress is caused in some people when the oxygen content falls to less than 13 per cent. Rapid breathing is produced much more quickly by an excess of carbon dioxide than by a corresponding deficiency of oxygen. The important point to remember is that rapid breathing caused by carbon dioxide starts long before there is any serious danger, whereas rapid breathing caused by a deficiency of oxygen is a grave symptom and points urgently to serious danger.

By acclimatization people live the year round at high altitudes where the air has an oxygen content, by weight, that is the same as that of an atmosphere at sea level containing 12 per cent oxygen by volume. People unaccustomed to such atmospheres, if suddenly plunged into them, experience severe distress. In an experiment conducted by the authors a man lost consciousness temporarily when the oxygen content of an atmosphere he breathed fell to 7 per cent.

Mice and canaries are about as resistive to low-oxygen atmospheres as men; hence they can not be used by exploring parties to give warning of atmospheres that are dangerously low in oxygen.

An excess of oxygen or a diminution of oxygen such as often occurs in many mines, if present in buildings above ground where people congregate, would be indicative of extremely bad ventilation. However, in mines having such an excess or diminution the ventilation may be excellent. In most buildings above ground, the problem of good ventilation is not to correct a diminished content of oxygen or an increased content of carbon dioxide, but to maintain proper temperature and relative humidity, and to keep the air moving, although the presence of an excessive proportion of carbon dioxide, more than 0.1 or 0.2 per cent, may be a reliable indication of air that will produce injurious effects on men. In these buildings the carbon dioxide comes chiefly from the air exhaled by the persons present, and, if fresh air is not admitted, invariably accompanies bad conditions such as stagnant and oppressive air, high temperature, and frequently high humidity. In coal mines the carbon dioxide is principally from the action of the oxygen of the air on the coal, and 0.2 per cent is frequently found in the cool, swiftly moving air of returns where 50,000 or more cubic feet of air is passing per minute. Hence, a proportion that accompanies good conditions of ventilation in a coal mine may indicate extremely poor conditions of ventilation in the room of a house.

A similar statement applies to oxygen. The oxygen content is scarcely ever normal in a coal mine, owing to the gas being absorbed by the coal; in fact, a diminution of 1 per cent is not uncommon. Such a diminution in a building filled with people would be accompanied by intolerable conditions of ventilation. However, even in coal mines the oxygen content of the air should not be allowed to become too low, and the authors believe that it should not fall below 19 per cent. That this limit can easily be maintained in coal mines is indicated by many mine-air analyses made by the authors. The maximum percentage of carbon dioxide allowed in English coal mines is 1.25 per cent.

The principal cause of the depletion of oxygen in coal-mine air and the increase of carbon dioxide is the reaction between the oxygen of the air and coal. Some of the oxygen is actually held dissolved in the coal substance. Part of the oxygen is converted into water, part into carbon dioxide, and part (by far the larger part) is retained as combined oxygen to give compounds richer in oxygen than the coal itself. Part of the carbon dioxide is retained by the coal.

Explosive proportions of methane in air become nonexplosive when the proportion of oxygen in the atmosphere falls below about 14 per cent. Carbon dioxide has only a slightly greater effect in reducing the explosibility of methane-air mixtures than nitrogen has; for instance, when the oxygen is kept constant at 20 per cent, part of the nitrogen must be replaced by 10 per cent of carbon dioxide to raise the low limit for methane from 5.8 to 6.2 per cent.

The specific gravity of black damp varies considerably in certain mixtures. When methane is present the combined gases may be lighter than air. Great caution should be observed when one detects an accumulation of black damp of lighter density than air, especially in coal mines in which naked lights are used, as this lesser density is probably due to the presence of methane.

Except directly over a fire area or close to a mine fire, a large proportion of carbon dioxide (more than 3 to 5 per cent) is unusual in the air of a coal mine.

An oil-fed flame becomes extinguished when the oxygen in air falls to about 17 per cent; an acetylene flame is extinguished when the oxygen falls to about 12 or 13 per cent.

Lack of oxygen is the important factor in extinguishing lights. In some experiments conducted by the authors, the oxygen content fell to 16.3 per cent before the flame became extinguished, but the presence of 10 per cent of carbon dioxide raised the extinguishing percentage of oxygen to 17.3.

Atmospheres that do not contain enough oxygen to support an oil-fed flame (about 17 per cent) may be explosive when the oxygen content is as low as 14 per cent, if enough methane is present.

When a burning part of a mine has been successfully sealed the composition of the atmosphere within changes. The oxygen decreases to a proportion (probably about 17 per cent) that will not support flame; ultimately the oxygen content becomes so small that the rate of combustion is extremely low, so low that combustion entirely ceases, the embers cool, and the admission of air when the mine is reopened does not rekindle them.

In 111 samples of gas from 29 mines represented, the average percentage of carbon dioxide in the black damp was 11.5 per cent, and the average percentage of nitrogen 89.5 per cent.

In 6 mines of 22 examined the temperature was higher than it should be (75° F., wet bulb) under the best ventilating conditions.

Analyses of a large number of samples, show how mine air changes as it traverses the workings. The average composition of the black damp was 9.2 per cent carbon dioxide and 90.8 per cent nitrogen. Except for two or three samples, in which carbon dioxide was high and the oxygen low, the quality of the air was good.

As regards the unfavorable effect of black damp on men, on lights, and on the explosibility of methane-air mixtures, the diminution of oxygen in the atmosphere, resulting in the formation of more nitrogen, is mainly responsible. The presence of carbon dioxide is far less important; hence the objection to making the terms "black damp" and "carbon dioxide" synonymous.

Many of the mines of the Cripple Creek region are menaced with gas that is loosely held in the rock strata and that issues at times into the mines, so that workmen can not enter certain drifts and occasionally a whole mine.

This gas, according to Lingren and Ransome, is of deep-seated origin and probably represents the last exhalations of the extinct Cripple Creek volcano. It contains about 14 per cent carbon dioxide and 86 per cent nitrogen. The gas is confined in the rock strata under very low pressure, so that changes in outside atmospheric pressures affect its outflow.

A limited number of observations made by the authors indicate that the direction of the wind influences the outflow of the gas.

Data regarding ventilation conditions in 15 metal mines other than the Cripple Creek mines are shown. The average percentage of black damp found in these mines was 2.67 per cent. The average composition of the black damp was 9.3 per cent carbon dioxide and 90.7 per cent nitrogen, or about the same as that found in coal mines. In general, the composition of the air in these metal mines, as shown by the carbon dioxide and oxygen content, were good. Difficulty is experienced, however, in keeping down the wet and the dry bulb temperature. In many cases the temperatures were so high as to be detrimental to health.

PUBLICATIONS ON MINE ACCIDENTS AND METHODS OF COAL MINING.

Limited editions of the following Bureau of Mines publications are temporarily available for free distribution. Requests for all publications can not be granted, and applicants should select only those publications that are of especial interest to them. All requests for publications should be addressed to the Director, Bureau of Mines, Washington, D. C.

BULLETIN 17. A primer on explosives for coal miners, by C. E. Munroe and Clarence Hall. 61 pp., 10 pls., 12 figs. Reprint of United States Geological Survey Bulletin 423.

BULLETIN 20. The explosibility of coal dust, by G. S. Rice, with chapters by J. C. W. Frazer, Axel Larsen, Frank Haas, and Carl Scholz. 204 pp., 14 pls., 28 figs.

BULLETIN 42. The sampling and examination of mine gases and natural gas, by G. A. Burrell and F. M. Seibert. 1913. 116 pp., 2 pls., 23 figs.

BULLETIN 45. Sand available for filling mine workings in the Northern Anthracite Coal Basin of Pennsylvania, by N. H. Darton. 1913. 33 pp., 8 pls., 5 figs.

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BULLETIN 50. A laboratory study of the inflammability of coal dust, by J. C. W. Frazer, E. J. Hoffman, and L. A. Scholl, jr. 1913. 60 pp., 95 figs.

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TECHNICAL PAPER 14. Apparatus for gas-analysis laboratories at coal mines, by G. A. Burrell and F. M. Seibert. 1913. 24 pp., 7 figs.

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TECHNICAL PAPER 22. Electrical symbols for mine maps, by H. H. Clark. 1912. 11 pp., 8 figs.

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